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FUEL AND LUBRICATING OILS FOR DIESEL ENGINES

FUEL AND LUBRICATING OILS
FOR
DIESEL ENGINES

BY

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PREFACE

In the last few years the number of fuels suitable for Diesel engines has increased to such an extent that considerable difficulty is often experienced in finding a reliable guide on the subject. This book is intended mainly as a handbook for owners and engineers in charge of Diesel engines. It deals with liquid fuels in general, their origin, composition, and preparation for use. Special attention has been devoted to Diesel fuel oils proper, and it has been thought useful to give specifications of qualities and also directions for carrying out simple tests. The lubricating oils are so nearly related to the fuel oils that the book would have had to be considered incomplete if they had not been included. A further reason for treating fuel and lubricating oils in the same volume is that most of the methods of testing apply equally to both.

Besides some well-known standard books, the treatises on fuel oils by Constam and Schläpfer and the publications of the Bureau of Mines, Washington, have supplied valuable information.

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FUEL AND LUBRICATING OILS FOR DIESEL ENGINES

I.—FUELS.

1. THE PRINCIPAL VARIETIES OF LIQUID FUELS. COMPOSITION AND TREATMENT OF THE RAW PRODUCTS.

A. Petroleum and Petroleum Products.

Already in very early times an oil-like combustible liquid was known, which oozed from the earth in small quantities and generally appeared as a thin film on water pools. Such "earth oils" were collected in the most primitive way: they were simply skimmed off. It is said that even in remote times one knew that it was possible to obtain valuable products by distilling the black, smeary liquid thus collected.

It may be taken for certain that, long ago, men had some idea of the existence of enormous quantities of mineral oil in the depths of the earth, but the technical appliances necessary for exploiting these treasures were lacking. In the course of time shafts were indeed sunk and the production of mineral oils thus increased; but by these primitive methods great depths could not be reached. Not until the middle of last century was it found possible to attain great depths, and the methods introduced then are in principle the same as those used to-day. That period was characterised by the first attempts in Pennsylvania to get at the oil-bearing strata by so-called bore-holes, 4 to 8 inches in diameter, drilled down to a depth of several hundred feet. Oil-raising appliances were lowered into the wells, and the liquid which flowed abundantly towards the well was thus brought to the surface. In such wells the pressure in the interior of the earth is

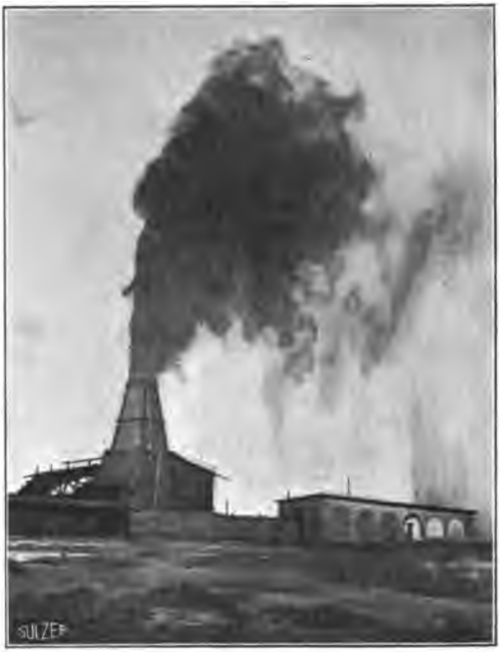

FIG. 1.—OIL GUSHER.

sometimes so great that the oil is forced out with great vehemence, forming what is known as a "gusher" (Fig. 1). This method of getting the oil has since become general. Vast oil fields have been discovered in many parts of the world, and some of the wells attain a depth of over 3,000 feet.

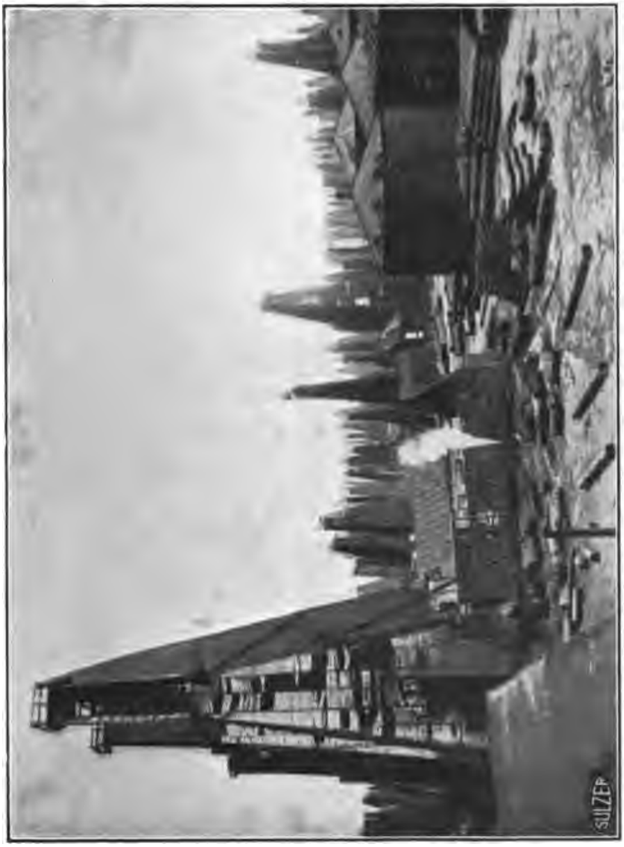

Fig. 2.—Oil Derricks at Baku.

The following tables give a summary of the size and geographical distribution of the world's oil fields and the development of the production in the United States.

PETROLEUM PRODUCTION IN 1915.

Country.	*Tons.*	*Per Cent.*
United States ..	40,478,991	65·85
Russia	9,870,921	16·06
Mexico	4,739,113	7·71
Roumania	1,732,307	2·81
Dutch East Indies ..	1,783,700	2·90
India	1,065,600	1·73
Galicia	598,882	0·98
Japan	449,058	0·73
Peru	358,164	0·59
Germany	143,390	0·23
Egypt	31,935	0·05
Trinidad	108,000	0·18
Canada	31,027	0·05
Italy	5,695	0·01
Other countries ..	75,761	0·12
Total	61,472,544	100·00

PETROLEUM PRODUCTION IN THE UNITED STATES.

Year.	*Barrels.*	*Tons.*
1859	2,000	200
1865	2,497,700	324,500
1870	5,260,745	684,000
1875	12,162,514	1,580,000
1880	26,286,123	3,420,000
1885	21,858,785	2,842,000
1890	45,823,572	5,960,000
1895	52,892,276	6,880,000
1900	63,620,529	8,280,000
1905	134,717,580	17,520,000
1910	209,556,048	27,940,000
1916	300,767,000	41,000,000

Composition and Treatment of Crude Oil.

Besides a certain percentage of water—often very high—and a smaller quantity of mineral solids, crude oil contains a series of various kinds of oils, differing from each other principally in specific gravity. When such oils are heated, a certain connection is found to exist between their specific gravities and their boiling-points. The lighter grades have a comparatively low boiling-point, and the specific gravity and temperature of boiling rise together fairly regularly. For instance, petrols with a specific gravity of about 0·7 boil between 50° and 100° C., kerosenes with a specific gravity of 0·79 to 0·82 mostly between 150° and 250° C., while heavy oils with a specific gravity of 0·9 to 0·95 boil at over 300° C.

All processes for obtaining the various grades of oil are founded on this fact. If a vessel be filled with crude oil and the temperature gradually raised, first the *light* grades (besides water) are volatilised, after these the *medium* oils, and finally the *heavy* grades. A pitch-like mass remains, from which still heavier oils may be abstracted by further heating, until finally a solid coke-like residue called *petroleum coke* is left.

The oil vapours pass into condensers, where they are liquefied, and thus the various grades are successively obtained. They are called fractional distillates and still show rather heterogeneous composition, and require further treatment in distilling plants before a certain degree of purity and a constancy of specific gravity can be obtained. As by-products, semi-liquid and wax-like substances such as vaseline

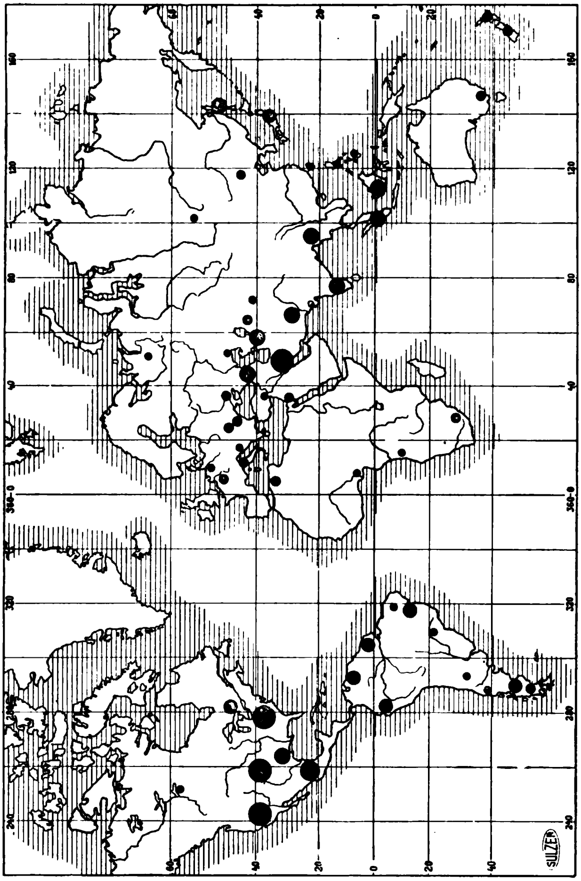

FIG. 3.—THE PRINCIPAL OIL FIELDS.

and paraffin wax—two valuable components of the heavy oil grades—are obtained by cooling. One particularly important process in refining is that which ultimately results in making the oil chemically pure. Petrols, kerosenes, and especially the lubricating oils, are repeatedly and thoroughly treated with acids, alkalies, and fuller's earth, principally in order to remove the asphaltic and resinous impurities.

THE PRINCIPAL PETROLEUM PRODUCTS.

Specific Gravity.	*Trade Names.*
0·60 to 0·69	Rhigoline, petroleum ether, gasoline.
0·69 to 0·73	Aviation spirit, petrol grades 1, 2, and 3.
0·73 to 0·79	Cleaning benzine, ligroin, heavy benzines, light kerosenes, varnish spirit.
0·79 to 0·82	Lamp oil, kerosene, standard white, water white, paraffin oil.
0·82 to 0·88	Gas oil, solar oil.
0·83 to 0·95	Lubricating oils, Diesel engine fuel, boiler firing oils, residues.*
0·80 to 0·88	Vaseline, petroleum jelly.
0·87 to 0·94	Paraffin waxes.

There is still much confusion in the nomenclature, the same name being often applied to quite different kinds of products. The ceaseless addition of new commercial names or " brands " only serves to increase the confusion, which is anything but an advantage to the consumer. The trade now tends to adopt general designations, with the addition of such a specification of properties as to prevent any misunderstanding, instead of employing vague names or " marks."

Residues*, which contain the smallest quantities of components with high boiling-points (pitch substances) are the most suitable for burning in Diesel engines, and the best class of Diesel fuel is obtained by further distillation, whereby pitch and coke are entirely eliminated. The methods of the petroleum industry are liable to great modifications according to the state of the market for the various products. When the price of lubricating oils is high, the heavy grade oils are completely refined and worked up into lubricants. On the other hand, if the demand for lubricants begins to weaken and the prices drop, while the demand for fuel oil increases, those fractions are not refined, but put on the market for fuel without further treatment.

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* See diagrams (b) and (c) on p. 10.

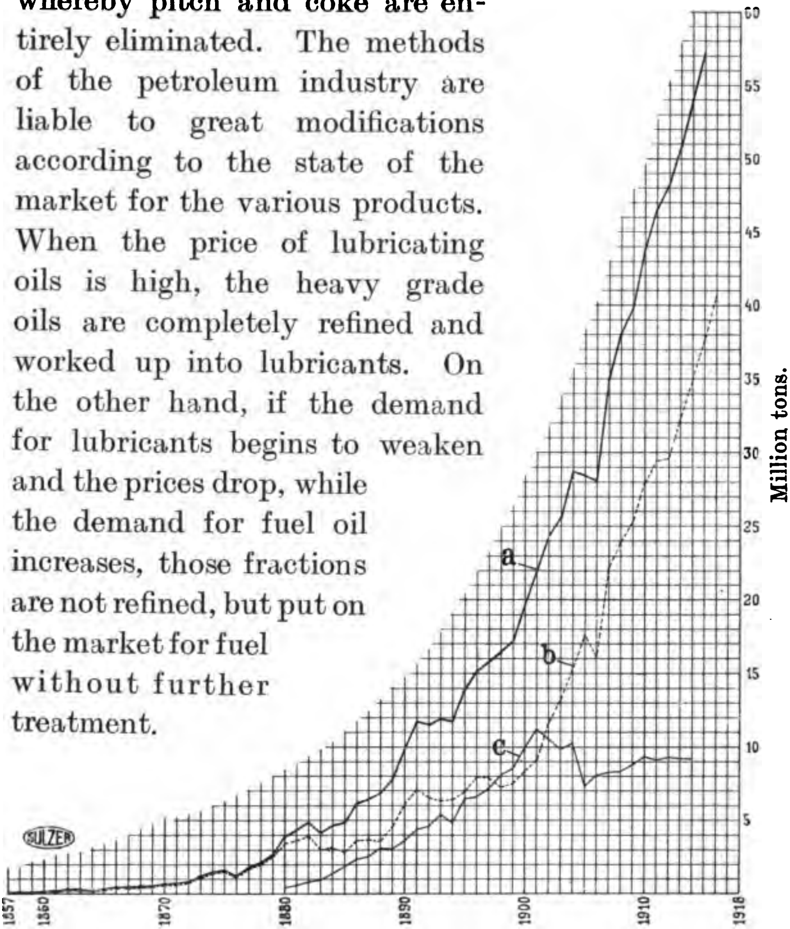


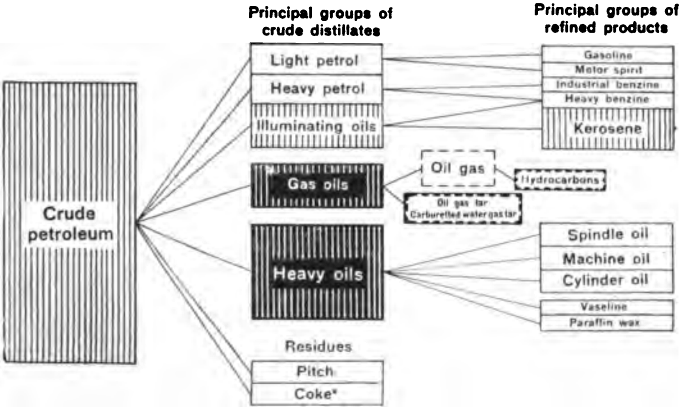
FIG. 4.—THE DEVELOPMENT IN PETROLEUM PRODUCTION.
a, Of the world; *b*, in the U.S.A.; *c*, in Russia

DIAGRAMS OF THE COMPLETE WORKING-UP OF PETROLEUM OILS.

CLASSIFICATION OF DIESEL FUEL OILS.

■	▥	⬚
Normal first-class fuel.	Partly medium and partly poor quality. Illuminating oils good, but too volatile.	Lowest quality of fuel. Not to be recommended.

(*a*) *Complete Scheme of Working-up.*

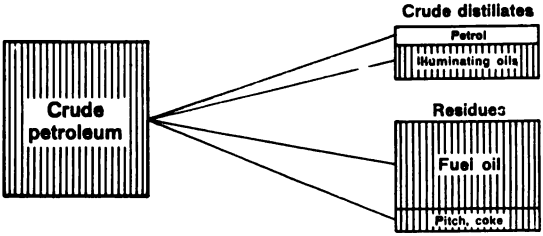


Lubricating oils can, of course, be used as Diesel engine fuel; at least, the cheaper sorts, and especially water-free used lubricating oils (waste oils), come into consideration in cases of necessity.

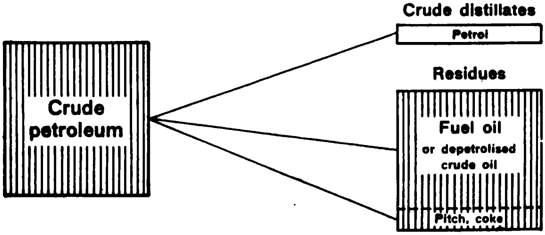
---

* Coke is not a constituent of petroleum, but a product of decomposition arising from the heating of the pitchy residue whereby the hydrogen constituents volatilise, and mostly carbon remains.

(*b*) *The Working-up of Petroleum into Petrol, Kerosene, and Fuel Oils.*



(*c*) *The Working-up of Petroleum into Petrol and Fuel Oils.*



Chemical Composition.

With the exception of the alcohols, all liquid fuels consist chiefly of compounds of carbon and hydrogen. In spite of the fact that these hydrocarbons are made up of two elements only, they comprise an immense number of varieties. Hundreds of such chemical compounds are known, representing as many variations in the proportions of the two elements or in the arrangement of their atoms. A peculiarity of the liquid fuels is that they generally do not consist only of one particular kind of hydrocarbon, but are, almost always, a mixture of a great number of different hydrocarbon compounds. Petroleum, for instance, is composed of hundreds of such compounds, and one particular group or another of related compounds may be predominant in it, but not according to any constant rule. Apparently the conditions of temperature and pressure under which the formation of petroleum took place must have been subject to great variations. We may also assume that the original matter* out of which these hydrocarbons were formed was not of a homogeneous nature. It follows that petroleum cannot be regarded as a chemical compound with any definite formula. As a rule, oils from different fields differ widely in composition; but this fact is not of great importance, as the suitability of an oil for burning purposes does not depend greatly on the particular varieties of hydrocarbons present.

All crude petroleums and most other liquid fuels contain, besides carbon and hydrogen, small quantities of oxygen, nitrogen, and sulphur, generally present in a state of chemical combination with each other. The presence of the three latter elements is undesirable, as they diminish the calorific value of the fuel and are unfavourable to good combustion.

AVERAGE COMPOSITION OF PETROLEUM.

	Per Cent. by Weight.
Hydrogen†	12
Carbon	86
Oxygen Nitrogen }	1
Sulphur	1
	100

---

* Most investigators are inclined to attribute the formation of petroleum to the decomposition of immense deposits of animal or vegetable remains. Others believe that steam and metallic carbides in the earth's crust were concerned in its production.

† The hydrogen content of light oils reaches 14 per cent., the carbon content being correspondingly less.

B. TARS AND OILS FROM LIGNITE (BROWN COAL) AND BITUMINOUS SHALES.

The tars obtained by the destructive distillation of lignite and certain bituminous shales resemble crude petroleum in many respects.

There are large firms in Scotland, France, Australia, and also in Central Germany, for the production and treatment of such tars. What these works are capable of producing is very small in comparison with the world's production of petroleum, and the fuel oil thus obtained and suitable for use in Diesel engines is such a small quantity that it is of no importance except in the particular country producing it.

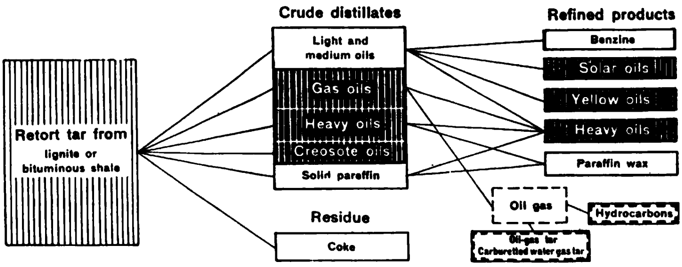
Lignite tar, not from retorts, but obtained directly from producers, is a poor fuel of similar qualities to raw coal tar.

Peat tar belongs to the same group as lignite tars.

DIAGRAMS OF THE WORKING-UP OF LIGNITE TARS AND CRUDE SHALE OILS.

CLASSIFICATION OF DIESEL FUEL OILS.

■	▥	⬚
Normal first-class fuel.	Seldom used. Not very suitable.	Lowest quality of fuel. Not to be recommended.



AVERAGE CHEMICAL COMPOSITION.

	Per Cent. by Weight.
Hydrogen	11·5
Carbon	86·5
Oxygen Nitrogen	1·2
Sulphur	0·8
	100·0

C. COAL TARS.

Coal, when heated to a high temperature in retorts from which air is excluded, is decomposed into solid, gaseous, and liquid products. The solids are the well-known gas and oven cokes; the gaseous products are represented by the important illuminating gas and by coke oven gas; the liquids comprise ammoniacal liquor and coal tar.

From 1 ton of coal there is obtained on the average:

14 cwt. coke;
0·6 to 2·0 cwt. ammoniacal liquor;
0·6 to 1 cwt. tar, mixed with a small percentage of ammoniacal liquor;
10,500 cubic feet (approximately) illuminating gas and benzol vapour.

The principal object of the process is either—

(*a*) the production of coke (in coke oven plants), or

(*b*) the production of illuminating gas (in gas works).

In both cases tar is obtained as a by-product.

Coal tar is a deep black to brownish-black viscous liquid with a strong characteristic odour. It is a mixture of more than 200 different chemical substances. A small part of the liquid consists of ammoniacal liquor. The oils compose the most valuable part. They are mostly hydrocarbons of a

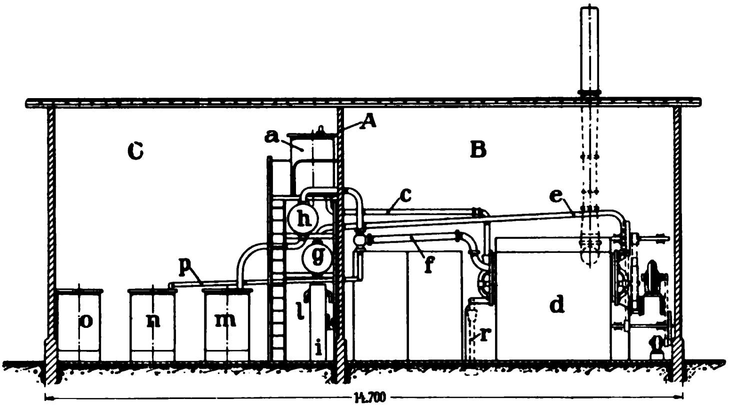


Fig. 5.—Sulzer Tar Distilling Plant.

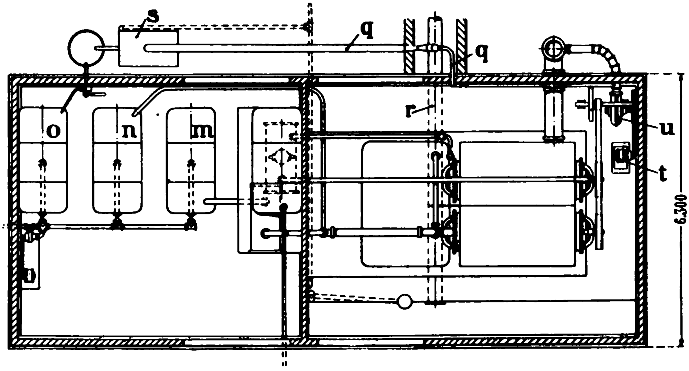


Fig. 6.—Sulzer Tar Distilling Plant.

specific gravity of 0·87 to 1·1, and contain also certain compounds of carbon, hydrogen, and oxygen, called " phenols," and excellent for preserving wood.

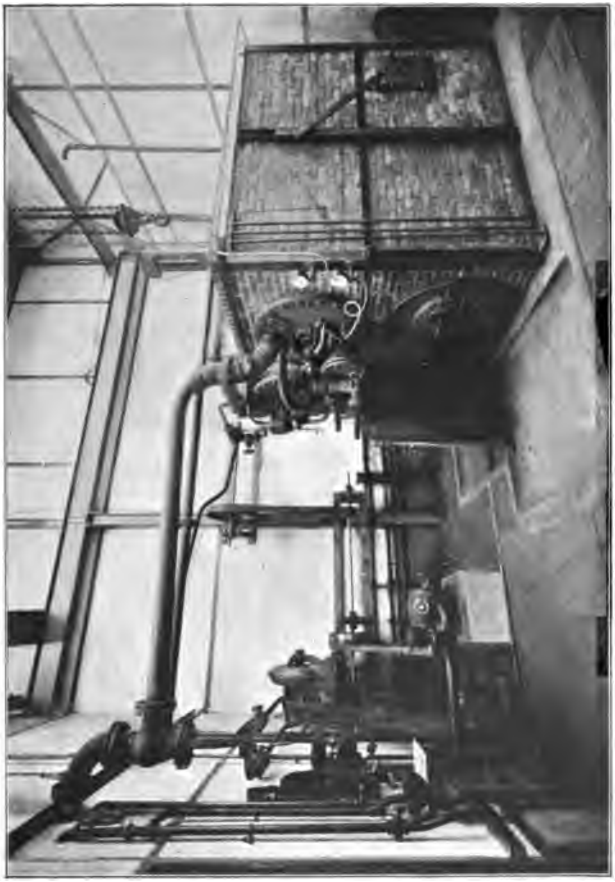


FIG. 7.—SULZER TAR DISTILLING PLANT.

The greater part of the tar, up to 60 per cent., consists of a mixture of viscous oils and free carbon, the so-called coal tar pitch, which is of little value in comparison with the lighter oils whose presence maintains it in a liquid state in the crude tar. The effect of distillation is to remove these light oils, and the coal tar pitch separates out as a substance which is liquid at high temperatures, but solid and even brittle when cold. The less pitch contained in the tar, the more mobile it is, and at the same time the more valuable.

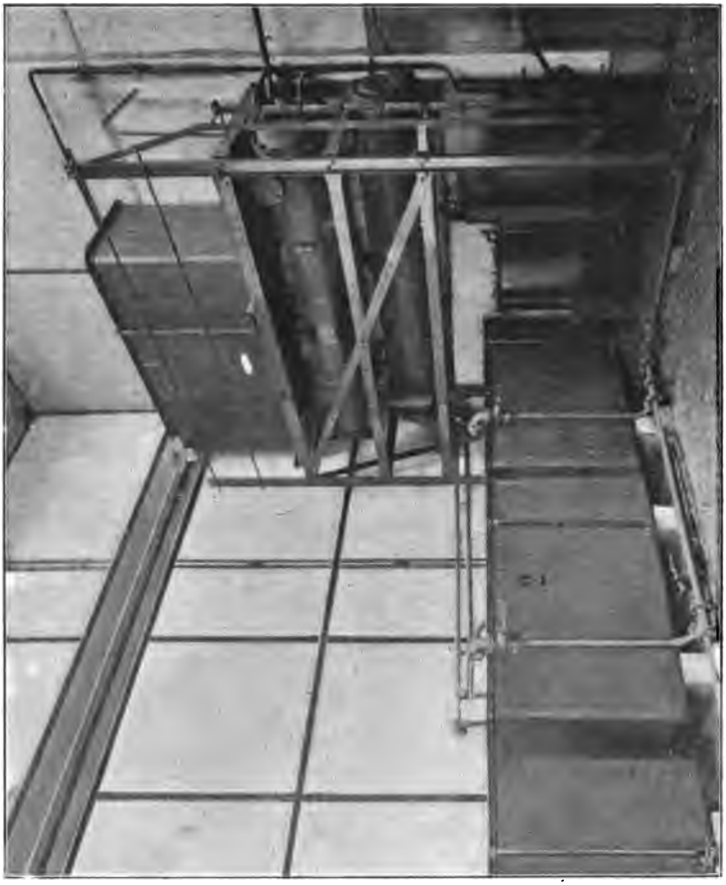


Fig. 8.—Sulzer Tar Distilling Plant.

It is singular that the quality of the tar is dependent less on the nature of the coal distilled than on the type of retort or oven employed and on the conditions under which the retort is worked. Vertical retorts produce a very fluid tar, while the product of horizontal retorts is viscous. The temperature at which the retort is worked has also a great influence on the quality of the tar; low temperatures give less pitch content, while high temperatures produce a tar with a greater proportion of the less valuable components. Temperature also affects the quantity of tar produced; higher coking temperatures result in reduced tar production.

COMPOSITION OF CRUDE TAR.

	Per Cent. by Weight.
Ammoniacal liquor	0 to 10
Oils	35 to 60
Pitch	30 to 60

Whether a crude tar is suitable for Diesel fuel or not depends mainly on the percentage of pitch present. A high pitch content is unfavourable to good combustion. The presence of a considerable amount of free carbon is also very undesirable.

AVERAGE CHEMICAL COMPOSITION OF CRUDE COAL TAR.

	Per Cent. by Weight.
Hydrogen	6·0
Carbon	89·5
Oxygen Nitrogen }	4·0
Sulphur	0·5
	100·0

D. COAL TAR DISTILLATES.

Coal tar is separated by distillation into a small number of components, the so-called "fractions," which in their turn are separated by further distillation into a large number of tar products. These are the raw materials for great chemical industries, for manufacturing innumerable dyes and other preparations, especially pharmaceutical. These industries, although of enormous importance, use but a comparatively small part of the total output of tar distillates, while practically all the rest is used, partly for impregnating purposes, but chiefly as fuel.

Among the *light oils* benzol is to-day of considerable importance as a motor spirit. The *medium and heavy oils* are burned, either alone or mixed, in furnaces, but particularly in Diesel engines. These oils, which are put on the market under the general name of *tar oils*, are seldom of uniform composition, but are arbitrary mixtures of various fractions: their calorific value increases as the percentage of phenols decreases.

Figs. 5 to 8 illustrate a tar distilling plant on the Sulzer system, and particularly suitable for the production of tar oil for Diesel fuel.

From the storage tanks the crude tar is conducted to the measuring tank *a* (Figs. 5 and 6), and thence to the still *d*, which consists of two horizontal cylinders. In the first cylinder are distilled ammoniacal liquor and light oils; in the second, the medium and heavy oils. The pitch residue is at a temperature of about 350° C. when discharged from the still, and is consequently quite fluid. It flows in a continuous stream through the pipe *r* into the pitch bay, where it solidifies. *g* and *h* are condensers for the oil vapours, *m*, *n*, and *o* receptacles for the tar oils obtained.

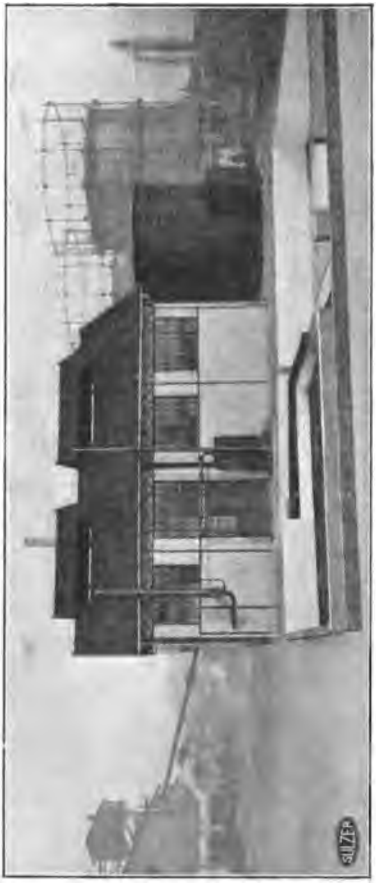


Fig. 9.—Gas Works equipped with Sulzer Tar Distilling Plant.

Figs. 7 and 8 are photographs of the plant. Fig. 9 gives a view of a complete distilling plant on the Sulzer system carried out for a gas works. The capacity of this plant is 8 to 10 tons of tar oil per twenty-four hours.

Such plants are suitable for municipal undertakings, where the gas works supply the fuel for the Diesel engines in the power stations (electric, pumping, etc.). In this way, not only are the Diesel engines made independent of an outside fuel supply, but the tar in the gas works is used up in the most efficient manner possible.

The Principal Fractions of Coal Tar Oils.

	Specific Gravity.	*Distilling Temperature.*
First runnings or crude naphtha ..	0·920	Up to 110° C.
Light oil	0·995	110 to 200° C.
Crude carbolic oil	1·015	200 to 240° C.
Creosote oil	1·050	240 to 270° C.
Anthracene or heavy oil	1·095	Above 270° C.

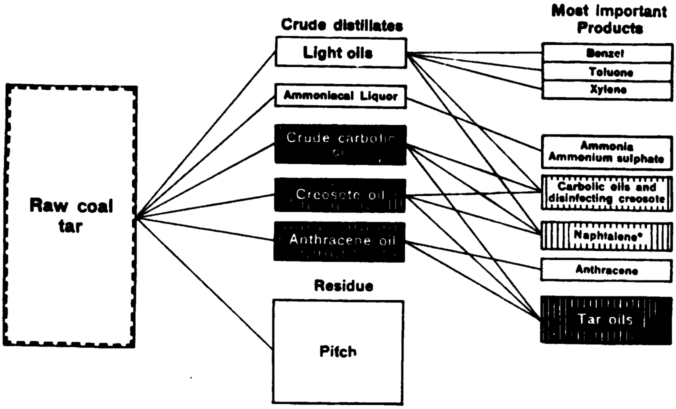
Each of these fractions is composed of a mixture of oils whose individual specific gravities lie partly below these average figures and partly above them. Each fraction therefore contains some proportion of members of the next higher and lower fractions.

The explanation for this imperfect separation is to be found in the physical fact that when mixtures of liquids with different boiling-points are distilled, part of those of higher boiling-point are driven over simultaneously with those of lower boiling-point.

Simplified Diagram of the Process of Tar Distillation.

Classification of Diesel Fuel Oils.

■	▥	⬚
Normal first-class fuel.	Used in exceptional cases.	Lowest quantity of fuel. Not to be recommended.



AVERAGE CHEMICAL COMPOSITION OF COAL TAR OILS.

	Per Cent. by Weight.
Hydrogen	6·5
Carbon	89·0
Oxygen Nitrogen	4 0
Sulphur	0·5
	100·0

E. OIL GAS TAR AND CARBURETTED WATER GAS TAR.

Oil gas is an illuminant of high value, and is obtained from the petroleum or lignite tar distillate, " gas oil," by decomposition at a high temperature. This gas is often used directly for the lighting of railway carriages, but still more as a means of carburetting the so-called " water gas," which in itself has very poor illuminating properties. In the first case the oil is generated in special retorts, and in the second the change of the gas oil into the gaseous state is brought about directly in the producer. In both processes tars of good quality are obtained as a by-product. They are very similar in property to the ordinary coal tars, but contain less free carbon than the latter. The fact that they contain only insignificant quantities of oxygen and nitrogen is in their favour, but on the other hand there is generally a considerable admixture of water, which detracts from their value.

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* The use of naphthalene as a Diesel engine fuel presents considerable difficulties, as this substance only liquefies at a temperature of about 80° C. In case of breakdown of the heating arrangements the fuel pipes might therefore become blocked. On the other hand, naphthalene is soluble in the other tar oils if their temperature be not too low, and in this state it can easily be used as a fuel.

AVERAGE CHEMICAL COMPOSITION.

	Per Cent. by Weight.
Hydrogen	6·5
Carbon	91·5
Oxygen Nitrogen	1·0
Sulphur	1·0
	100·0

A by-product in the making of compressed oil gas is a liquid condensed from very light oil vapours. These hydrocarbons belong to the same class of very light coal tar distillates as benzol and toluol, and can be used as fuel for Diesel engines; but, as experiment has proved, some difficulty is caused by their extreme liquidity and volatility. When running lightly loaded the engine requires ignition oil. Care must be taken that the storage tanks are gas-tight, as the vapours given off are highly inflammable and possess an extremely nauseous smell.

F. VEGETABLE OILS.

All vegetable oils are very suitable for burning in Diesel engines, and may be used whenever their cost permits them to compete with mineral oils; but this will only be the case under quite exceptional conditions.

Among the varieties which are available in quantity are—

- Arachis oil (peanut oil)
- Sesame oil.
- Rape oil.
- Palm oil.
- Olive oil.
- Cottonseed oil.
- Castor oil.

AVERAGE CHEMICAL COMPOSITION.

	Per Cent. by Weight.
Hydrogen	11·5
Carbon	76·0
Oxygen Nitrogen	12·5
Sulphur	0·0
	100·0

G. ALCOHOLS.

Among the alcohols there are only two which come into consideration—namely, ethyl alcohol and methyl alcohol.

Ethyl Alcohol (spirit of wine) is produced by the fermentation of a solution of vegetable substances which contain sugar (fruit, cereals, potatoes). The resultant mixture of water and alcohol is very weak, and is concentrated by distilling with a fractionating column, but, under the most favourable circumstances, the water content is only reduced to between 10 and 5 per cent.; in other words, a 90 to 95 per cent. spirit is obtained. Ethyl alcohol can also be produced from the waste liquor from paper pulp works (sulphite liquor). Within recent years efforts to produce alcohols synthetically have been successful. Acetylene is generated from calcium carbide made in the electric furnace, and from this gas ethyl alcohol is prepared by various chemical processes.

Methyl Alcohol.—The destructive distillation of wood results in a large yield of various liquids, including, besides an admixture of water, tar oils, acetic acid, and *methyl alcohol* (wood spirit).

The alcohols are compounds of carbon, hydrogen, and oxygen. Absolutely pure alcohol—*i.e.*, alcohol free from any trace of water—is only employed for special purposes. For use as fuel the considerably cheaper industrial spirit of 90 to 95 per cent. alcohol content is used. Alcohols are suitable for burning in Diesel engines only under certain conditions; the delivery of the fuel pump, for instance, must be made larger, because the calorific value of alcohol volume for volume is much lower than that of other Diesel fuels.

1 litre petroleum has a calorific value of 9,000 calories.
1 litre coal tar oil ,, ,, 9,400 ,,
1 litre vegetable oil ,, ,, 8,200 ,,
1 litre 90 per cent. ethyl alcohol has a calorific value of 4,720 calories.
1 litre 90 per cent. methyl alcohol has a calorific value of 3,300 calories.

Unlike all other liquid fuels, the alcohols have a definite chemical composition. The alcohol sold for industrial purposes contains considerable quantities of related compounds, such as amyl alcohol, propyl alcohol, butyl alcohol, etc., known collectively as " fusel oils." Further, there are the added denaturising agents; while methyl alcohol contains small quantities of acetone.

CHEMICAL COMPOSITION OF PURE ALCOHOL.

	Per Cent. by Weight.		
	Hydrogen.	*Carbon.*	*Oxygen.*
Ethyl alcohol	13·0	52·0	35·0
Methyl alcohol	12·5	37·5	50·0

SYNOPSIS OF CHEMICAL COMPOSITION.

	Per Cent. by Weight.			
	Hydrogen	*Carbon.*	*Oxygen and Nitrogen*	*Sulphur.*
A. Petroleum and petroleum products	12	86	1	1
B. Lignite tar and shale oil products	11·5	86·5	1·2	0·8
C. Raw coal tar ..	6	89·5	4	0·5
D. Coal tar distillates ..	6·5	89	4	0·5
E. Oil gas tars and carburetted water gas tars	6·5	91·5	1	1
F. Vegetable oils ..	11·5	76	12·5	—
G. Alcohols			Oxygen.	
90 per cent. ethyl alcohol	12·8	46·7	40·5	—
90 per cent. methyl alcohol	12·3	33·8	53·9	—

2. FUEL OILS FOR DIESEL ENGINES.

TRADE NAMES, PROPERTIES, CLASSIFICATION AND SPECIFICATIONS.

The foregoing chapter being intended to give some idea of liquid fuels in general, we shall now deal in particular with those specially suitable for use in Diesel engines. From the trade name some approximate conclusions as to the properties of an oil may generally be drawn, yet in forming these conclusions care must be exercised, because, as already mentioned, one and the same name is often applied to quite different oils.

In spite of the fact that very poor liquid fuels are now used in Diesel engines, and generally without any alteration to the injection arrangements, there are still certain limitations in the use of such fuels. Engines running on poor fuel demand more skilled and careful attendance, and greater wear and tear on some parts of the mechanism must be reckoned on. These circumstances must be taken into consideration when the quality of the fuel approaches the minimum figures given in the following tables, or even falls below them.

Notes for the Tables on the following pages.

(1) This also includes oils which cannot be used at all, or only with difficulty.

(2) Specification for ordering.

(3) The limits of specification (2) should not be exceeded unless very exceptionally.

A. PETROLEUM, PETROLEUM DISTILLATES AND RESIDUES.

Specific Gravity at 20° C.	*Trade Names.*
	Crude Petroleum.
0·80 to 0·97	Crude oil, crude petroleum, naphtha (Russian).
	Residues.
0·85 to 0·97	Depetrolised crude oils, Galician gas oil.
0·88 to 0·97	Distillation residues, furnace oil, Mazut, Pacura, liquid fuel, fuel oil, residua, cracking naphtha.
	Distillates.
0·83 to 0·88	Gas oil, solar oil, blue oil, vaseline oil, fuel oil.
	Refined Distillates.
0·79 to 0·82	Lamp oil, kerosene, paraffin oil.

PROPERTIES.

	Approximate Limits. (1)	*For Use in Diesel Engines.*	
		To be Specified (2)	*Admissible.* (3)
Specific gravity at 20° C.	0·79 to 0·97	0·8 to 0·97	0·8 to 0·97
Flash point (open test)..	0° to 170° C.	over 65°C.	20° C. and over
Viscosity at 50° C. Engler degrees	1·5 to 200	below 5	up to 80
Viscosity Redwood I at 120° F. seconds	45 to 6,000	below 150	up to 2,400
Net calorific value (undried sample), calories per kilogram	8,500 to 10,200	10,000	9,600 and over
Ash content, % by wt.	0 to 0·5	below 0·05	not over 0·01
Sulphur content, % by wt.	0 to 5	not over 2	not over 3
Residue at 400° C. (pitch), % by wt.	0 to 25	not over 5	not over 15
Water content, % by wt.	0 to 10	not over 1	not over 5

Specific Gravity.—The only reason for stipulating a lower limit of specific gravity is to exclude the very volatile oils, such as the heavy benzines. Otherwise there would be no necessity for any stipulation as to specific gravity. One is therefore much more free in this respect than, for instance, with motor spirit, in which the specific gravity must lie between certain narrowly defined limits. But for the present it is desirable to mention the specific gravity, because certain physical properties stand in close relation to it.

Flash Point.—Oils with low flash point are likely to give off inflammable vapours, and therefore require special precautions in storage. For instance, lamp oil of a specific gravity between 0·79 and 0·82 has a flash point of from 20° to 40° C., and is in many countries subjected to certain regulations. Besides the danger of fire, a low flash point has the disadvantage of making combustion unsteady or even explosive in character. It is not necessary to state an upper limit for the flash point, as it can never be too high.

Viscosity.—In cases where the viscosity exceeds 5 degrees Engler at 50° C., means should be provided for slightly preheating the fuel, especially during cold weather. This can be done by fixing heating coils in the storage tank, and by sending the warm circulating water of the engine through them. Very thick oils always require some heating. When using thick oils the engine should always be started up with a thin gas oil of a viscosity of about 1·5 to 2·5 degrees Engler at 50° C. (=45 to 75 seconds Redwood I at 120° F.). Oils containing paraffin-wax have a tendency to become semisolid in cold weather, but seldom require special arrangements for pre-heating, as the temperature of the engine-room is generally sufficiently high to ensure them being fluid enough.

Calorific Value.—This factor is important, inasmuch as the fuel consumption of the engine depends upon it. The lower the calorific value, the greater is the consumption of fuel. Oils of lower specific gravity are of high calorific value, high gravity oils always somewhat lower.

Ash Content.—This value is a measure of the mineral impurities present, which often cause abrasion in the engine. A high ash content increases the wear and tear of the piston rings and of the cylinder; and it is therefore important that the ash content should be as low as possible, and not more than 0·05 per cent. Distillates contain, as a rule, only small quantities of very fine impurities which cannot be removed by filtration, but crude oils and distillation residues often contain even coarse-grained sand which has come from the interior of the earth. A high percentage of abrasive impurities lowers the value of an oil considerably.

Sulphur Content.—Among the oils from fields at present known, only the Mexican and Californian have a high sulphur content (2 to 5 per cent.). The assumption which formerly prevailed that the sulphur content is detrimental has found but slight confirmation.

Exhaust gases containing sulphur should, however, be kept away from the compressor if the sulphur content of the fuel exceeds 1 per cent., as the condensation of acid vapours may cause corrosion inside the compressor. This danger may arise, for instance, if the working pistons or the exhaust piping are not tight; combustion gases can then find their way into the engine room and to the air inlet of the compressor.

Residues.—If the percentage of residues is high, it may be taken as certain that combustion will be bad. The percentage of residues is ascertained by distilling a sample at temperatures up to 400° C. These residues are often described as "asphalt," but this is misleading, for the residues consist mostly of substances which are of quite a different character from natural asphalt. A better method of estimating the asphalt content is that indicated by Holde, based on the determination of those residues which are insoluble in an ether-alcohol mixture.

Water Content.—A considerable water content may cause some trouble in highly sensitive installations, as, for instance, electric power plants. Water always collects at the bottom of petroleum tanks, because the oil has a lower specific gravity.

B.—TARS AND OILS FROM LIGNITE AND SHALES.

Specific Gravity at 20° C.	*Trade Names.*
	Crude Tars.
0·90 to 0·98	Lignite tar, crude shale oil.
	Distillates.
0·90 to 0·96	Lignite tar oils, shale oils.
0·89 to 0·94	Scotch crude oil, huile de schistes bitumineux.
0·85 to 0·92	Paraffin oils, yellow oil.
0·82 to 0·83	Solar oil.
0·88 to 0·90	Gas oil.

PROPERTIES.

	Approximate Limits. (1)	*For Use in Diesel Engines.*	
		To be Specified. (2)	*Admissible.* (3)
Specific gravity at 20° C.	0·8 to 0·98	0·82 to 0·98	0·8 to 0·98
Flash point (open test)	20° to 110° C.	over 65° C.	20° C. and over
Viscosity at 50° C. Engler degree	1 to 2	—	—*
Viscosity Redwood I at 120° F. seconds	30 to 60	—	—*
Net calorific value (undried sample) calories per kilogram	9,500 to 10,000	9,900	9,600 and over
Ash content, per cent. by weight	0 to 0·1	below 0·05	not over 0·1
Sulphur content, per cent. by weight.	0 to 2	—	—*
Residue at 400° C. (pitch), per cent. by weight	2 to 10	not over 5	not over 10
Water content, per cent. by weight	0 to 10	not over 1	not over 5

(1), (2), and (3), see p. 26.

* The viscosity and sulphur content of the above group are always within the permissible limits See also pp. 28 to 30.

C.—COAL TARS.

(Not to be recommended.)

Specific Gravity at 20° C.	*Trade Names.*
1·1 to 1·18	Coke oven tar, inclined retort tar, horizontal retort tar.
1·06 to 1·12	Vertical retort tar, chamber oven tar.

PROPERTIES.

	Approximate Limits. (1)	*For Use in Diesel Engines.*	
		To be Specified. (2)	*Admissible.* (3)
Specific gravity at 20° C.	1·06 to 1·18	1·06 to 1·1	1·06 to 1·15
Flash point (open test)	30° to 130° C.	over 65° C.	30° C. and over
Viscosity at 50° C. Engler degrees	1·5 to 35	below 6	not over 10
Viscosity Redwood I at 120° F. seconds	45 to 1,000	below 180	not over 300
Net calorific value (undried sample), calories per kilogram.	8,000 to 9,000	8,800	8,600 and over
Ash content, per cent. by weight	0 to 0·5	below 0·05	not over 0·1
Sulphur content, per cent. by weight	0·4 to 1	0·4 to 1	—
Residue at 350° C. (pitch), per cent. by weight	30 to 65	not over 35	not over 40
Water content, per cent. by weight	0 to 10	below 2	not over 5
Free carbon, per cent. by weight	1 to 10	not over 2·5	not over 4

(1), (2), and (3), see p. 26

D.—COAL TAR DISTILLATES.

Specific Gravity at 20° C.	*Trade Names.*
1·06 to 1·12	Creosote oil, heavy oil, anthracene oil.
1 to 1·08	Tar oil.

PROPERTIES.

	Approximate Limits. (1)	*For Use in Diesel Engines.*	
		To be Specified. (2)	*Admissible.* (3)
Specific gravity at 20° C.	1 to 1·12	1·05	1 to 1·12
Flash point (open test)	30 to 120° C.	over 65° C.	30° C. and over
Viscosity at 50° C. Engler degrees	1·2 to 2	—	—
Viscosity Redwood I at 120° F. seconds	36 to 60	—	—
Net calorific value (undried sample), calories per kilogram	8,600 to 9,200	9,000	8,700 and over
Ash content, per cent. by weight	0 to 0·5	below 0·05	not over 0·1
Sulphur content, per cent by weight	0 to 1	0 to 1	—
Residue at 350° C. (pitch), per cent. by weight	1 to 35	not over 5	not over 20
Water content, per cent. by weight	0 to 6	not over 1	not over 5
Free carbon, per cent. by weight.	0 to 2	not over 0·1	not over 0·5

(1), (2), and (3), see p. 26.

E.—OIL GAS TARS AND CARBURETTED WATER GAS TARS.

(Not to be recommended, although better than coal tar.)

Specific Gravity at 20° C.	*Trade Names.*
1 to 1·1	Oil gas tar.
1 to 1·1	Carburetted water gas tar.

PROPERTIES.

	Approximate Limits. (1)	*For Use in Diesel Engines.*	
		To be Specified. (2)	*Admissible.* (3)
Specific gravity at 20° C.	1 to 1·1	1 to 1·05	1 to 1·1
Flash point (open test)	20° to 70° C.	over 65° C.	20° C. and over
Viscosity at 50° C. Engler degrees	1 to 2	—	—
Viscosity Redwood I at 120° F. seconds.	30 to 60	—	—
Net calorific value (undried sample), calories per kilogram.	7,000 to 9,500	9,100	8,800 and over
Ash content, per cent. by weight	0 to 0·5	below 0·05	not over 0·1
Sulphur content, per cent. by weight.	0 to 1·5	—	—
Residue at 350° C. (pitch), per cent. by weight	15 to 50	not over 25	not over 30
Water content, per cent. by weight.	0 to 25	0	not over 5
Free carbon, per cent. by weight.	0 to 5	not over 2	not over 4

(1), (2), and (3), see p. 26

In addition to the remarks on pp. 28 to 30 which refer to the fuel groups C, D, and E, the following points should be mentioned:

Calorific Value.—These oils are considerably lower in calorific value than petroleum, so that an increased consumption may be expected. Statistics of engines running in England show that although the calorific value of tar oils is on an average 12 per cent. lower than that of petroleum oils, the increase in fuel consumption is only 8 per cent. Thus a slightly higher thermal efficiency is usually obtained from tar oils.

Water Content.—Water disengaged from tars and tar oils rises to the surface, as the specific gravity of the latter is above 1. Sometimes the water contains sodium sulphate and is of high specific gravity, when it may be found at the bottom of the tank, even if the specific gravity of the oil is considerably over 1.

Free Carbon.—By this is understood soot-like, finely divided carbon. The presence of this slow-burning substance generally causes considerable fouling in the cylinder.

Influence of Low Temperature.—Crude tar remains liquid or turns into a homogeneous pasty substance at comparatively low temperatures. On the other hand, at low temperatures, tar distillates deposit a crystalline precipitate, consisting principally of naphthalene. This precipitate is easily dissolved by warming. The inconvenience of preheating is compensated by the high calorific value of naphthalene, and objections based on such separations are hardly justified.

Inflammability.—The fuels of groups C, D, and E are rather difficult of ignition in comparison with the fuels of groups A and B. Petroleum oils or lignite tar oils have spontaneous ignition temperatures between 400° and 500° C., whereas tar and tar distillates of the groups C, D, and E have spontaneous ignition temperatures of 600° to 650° C. It is well known that the ignition temperature in the Diesel engine is produced by the high compression of the combustion air, which therefore rises in temperature up to 550° to 650° C. Experience shows that when running at full load higher compression temperatures are developed. When the load is less, the compression temperature is also less, and misfiring is likely to occur if the oils used are difficult to ignite. In order to ensure that ignition takes place promptly, a so-called ignition device must be provided. This consists of an additional fuel pump supplying a small quantity of an easily ignitable oil (ignition oil), which additional charge is forced into the lower part of the fuel valve. Four-cycle engines especially are likely to give trouble by misfiring. Two-cycle engines are much better in this respect, and only require ignition devices in quite exceptional cases. Diesel engines running on coal tar oil must always be started up on petroleum, lignite tar or shale oil, and this must be employed until the engine is thoroughly warmed up. For the same reason reversible engines require to be run on such an oil when starting up, and, for safety, during the reversing period. Thoroughly warm two-cycle marine engines can, however, be safely reversed on coal tar oil.

The Use of Crude Tar.—Crude tars, even of the better kinds, are poor Diesel fuels, and can only be recommended in cases where the running conditions are favourable. The load on the engine should be practically constant, and not fall below one-quarter, nor rise much above three-quarters, of the "normal load."* Particular attention must be given to the attainment of perfect combustion, as otherwise the cylinders may be badly fouled by sticky and resinous tar deposits. Messrs. Sulzer Bros. recommend a special brand of cylinder oil which prevents the fouling of the working surfaces of the piston.

F.—VEGETABLE OILS.

Specific Gravity at 20° C.	*Trade Names.*
0·912 to 0·916	Arachis oil (pea nut oil).
0·920 to 0·924	Sesame oil.
0·909 to 0·913	Rape oil.
0·917 to 0·940	Palm oil.
0·910 to 0·916	Olive oil.
0·918 to 0·926	Cottonseed oil.
0·957 to 0·970	Castor oil.

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* The term "normal" or "nominal" load of the engine refers to the maximum horse power which the engine is capable of developing in continuous running. This figure is generally used for the rating of Diesel engines.

PROPERTIES.

	Approximate Limits. (1)	*For Use in Diesel Engines.*	
		To be Specified. (2)	*Admissible* (3)
Specific gravity at 20° C.	0·91 to 0·97	0·91 to 0·97	—
Flash point (open test)	150 to 300° C.	150° to 300° C.	—
Viscosity at 50° C. Engler degrees.	3·5 to 20	3·5 to 20	—
Viscosity Redwood I at 120° F. seconds.	100 to 600	100 to 600	—
Net calorific value (undried sample), calories per kilogram.	8,000 to 8,900	over 8,200	8,000 and over
Ash content, per cent. by weight.	0 to 0·05	—	0 to 0·05
Sulphur content, per cent. by weight.	0 to 0·1	—	—
Residue at 400° C., per cent. by weight.	0 to 5	below 5	up to 5
Water content, per cent. by weight.	0 to 10	not above 2	not above 5

(1), (2), and (3), see p. 26.

It should be noted that the above vegetable oils differ but little from each other, with the exception of castor oil, which shows considerable anomalies:

	Castor Oil.	*Other Kinds of Vegetable Oils.*
Specific gravity	0·96	about 0·92
Viscosity at 50° C. Engler degrees	20	3·5 to 5
Net calorific value, calories per kilogram.	8,300	8,700 to 8,900

All these oils, even when unrefined, are suitable for use in Diesel engines, and do not require any alteration of the fuel valves or gear. Some of them require warming. The high flash point has no influence on ignition.

Vegetable oils decompose when exposed to the air. They become dry and resinous, or turn rancid, and should therefore be stored in airtight vessels.

G.—ALCOHOLS.

Specific Gravity of Absolute Alcohol (Free from Water).	*Trade Names.*
0·794	Spirit, spirit of wine, ethyl alcohol
0·796	Wood spirit, methyl alcohol.

PROPERTIES.

	90 Per Cent. Ethyl Alcohol.	*90 Per Cent. Methyl Alcohol.*
Specific gravity at 15° C. ..	0·823	0·824
Flash point (open test) ..	18° C.	18° C.
Viscosity at 15° C. Engler degrees.	1	1
Viscosity Redwood I at 60° F. seconds.	30	30
Net calorific value, calories per kilogram.	5,730	3,990
Net calorific value, calories per litre.	4,720	3,300
Ash content, per cent. by weight.	—	—
Sulphur content, per cent. by weight.	—	—
Residue at 400° C., per cent. by weight.	—	—
Water content, per cent. by weight.	10	10

These fuels are very volatile, and in consequence easily inflammable; they must, therefore, always be stored in closed tanks.

Methyl alcohol is poisonous.

Calorific Value of Alcohol-Water Mixtures (Obtained by Calculation)

Ethyl alcohol .. %	100	95	90	85	80
Water content .. %	0	5	10	15	20
Specific gravity at 15° C.	0·794	0·809	0·823	0·836	0·849
Net calorific value, calories per kilogram.	6,440	6,080	5,730	5,380	5,030
Methyl alcohol %	100	95	90	85	80
Water content .. %	0	5	10	15	20
Specific gravity at 15° C.	0·796	0·810	0·824	0·837	0·850
Net calorific value, calories per kilogram.	4,500	4,245	3,990	3,735	3,480

The Physiological Action of Fuel Oils and their Vapours.

As the result of many years' practical experience, it can be stated that the Diesel fuels now in use are not dangerous to health. The components of certain oils are to some extent irritant, but they have at the same time disinfectant qualities, as, for instance, the carbolic oils in coal tar oils. This implies that, under certain conditions, they have a directly hygienic effect. As a rule fuel oils are stored in closed tanks, and airtight pipes and apparatus make any direct contact with the oil very improbable. The possibility of inhaling the vapours can only concern quite insignificant quantities, as most of the fuel oils have very low volatility. Anyone employed about fuel storage tanks, etc., should nevertheless observe strict cleanliness. Frequent contact with fuel oils may produce slight skin affections on the hands and arms of sensitive persons. Ample ventilation should be ensured before entering the interior of large storage tanks for inspection or cleaning. It is strongly to be recommended that during the whole time that men are working inside the tanks efficient ventilation should be maintained by means of a ventilating fan, and that a man should be continually on watch outside and near the tanks in order to give assistance in case of gassing. On no occasion should lamps with open flame be used inside the tanks. Vaults and other enclosed spaces where fuel is stored should be constantly and well ventilated.

Methyl alcohol forms an exception to what has been said above, but this fuel has, up to the present, not been used for Diesel engines. It is highly volatile and poisonous, and its vapours are said to cause serious diseases of the eyes, and even blindness.

STORAGE APPLIANCES.

Iron tanks are generally very suitable for storing Diesel fuel, but concrete tanks are also gradually coming into use. The former are generally somewhat more expensive to build than the latter, but are best for storage above ground. Ferro-concrete tanks are generally lower in first cost, provided that suitable materials for the concrete are to hand. For these a situation below the ground level is advantageous. Their shape should be quite simple, and they should be on firm ground, otherwise uneven settling takes place, causing cracks and consequent leakage. The concrete work must be so carried out that the bottom and sides form one single piece (monolithic concrete). The floor and side walls should be lined with glass plates or covered by a coating impervious to oil; or, by another method which has given good results, a lining of sheet iron is fitted, autogenously welded together by a special process.

Fig. 10 shows a suitable arrangement for large iron tanks. In the basement is installed a tank of 20 to 25 cubic metres capacity which easily holds the contents of a railway tank wagon. This intermediate, or "quarantine," tank, as it might be called, is first filled directly from the tank wagon, so that the new oil delivered may be tested before it is pumped into the main storage tank.

This method ensures quick and convenient emptying of the wagons, and allows of each consignment being thoroughly tested, and even tried on the engine, before being stored with the main stock.

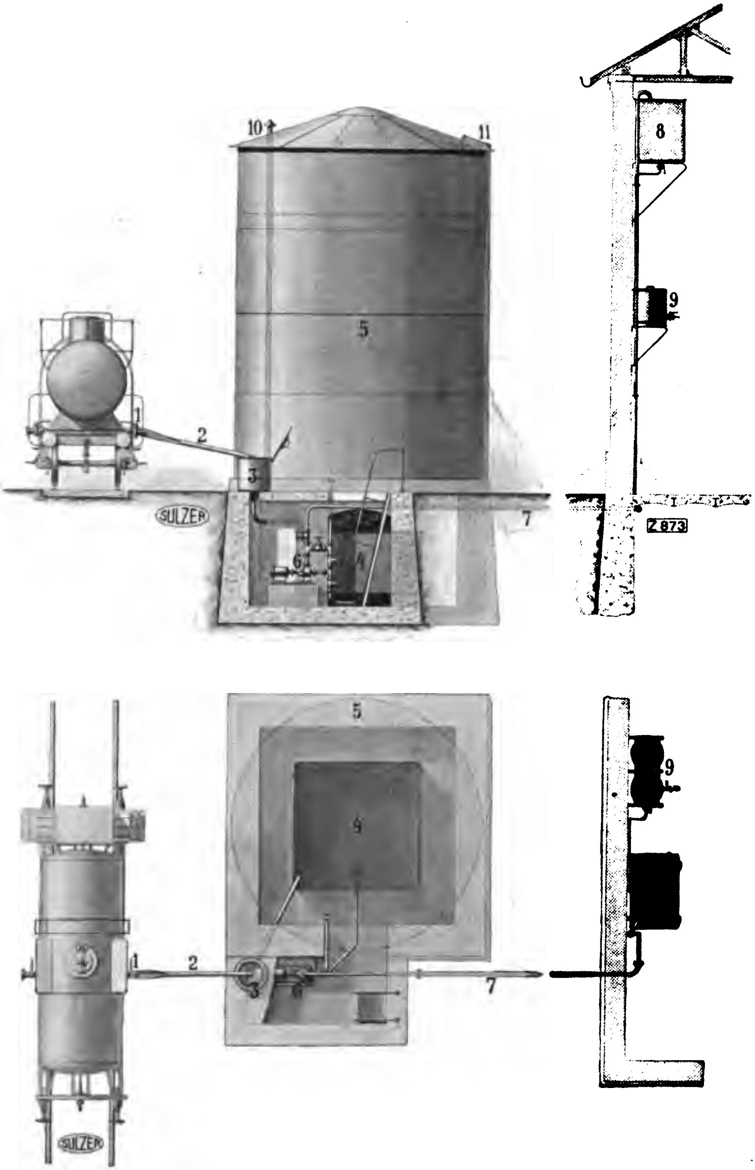

FIG. 10.—ARRANGEMENT FOR FUEL STORAGE.

1. Tap on Tank Wagon.
2. Movable Receiving-Pipe.
3. Receiving Funnel and Filter.
4. Intermediate Tank.
5. Main Storage Tank.
6. Centrifugal Pump.
7. Fuel Piping.
8. One-Day Storage Tank.
9. Service Tank.
10. Ventilating Pipe.
11. Oil-Level Indicator.

TESTS MADE BY THE SWISS FEDERAL

KIND OF FUEL.	PHYSICAL									
	Crude Oils.				*Distillation Test (Calculated for Ash*					
	Specific Gravity at 15° C.	*State when Cold.*	*Flash Point.*	*Burning Point.*	0–150° C.	150–200° C.	200–250° C.	250–300° C.	300–350° C.	350–400° C.
			° C.	*° C.*	%	%	%	%	%	%
GROUP A.										
Petroleum, Petroleum Residua and Distillates.										
Galician Oils.										
Diesel engine fuel oil ..	0·856	at 0° C. solid	90	130	—	2·3	11·9	42·5	36·0	6·6
Diesel engine fuel oil ..	0·882	at – 12° C. very viscous	112	135	—	0·5	6·5	43·0	50·0	—
Roumanian Oils.										
Diesel engine fuel oil ..	0·932	at 0° C. viscous at – 12° C. nearly solid	162	189	—	—	—	7·0	79·0	7·0 de-comp.
Heavy oil	0·948	at 0° C. viscous at – 15° C. buttery	142	172	—	—	3·0	13·5	69·5	5·5
Russian Oils.										
Special Diesel engine oil	0·881	at – 17° C. very viscous but still not solid	113	134	—	—	9·0	37·0	25·0	27·5
North American Oils.										
American fuel oil ..	0·890	at + 5° C. solid	166	200	—	—	—	0·8	41·5	55·5
Texas refuse oil ..	0·893	at 0° C. viscous at – 15° C. nearly solid	122	156	—	2·0	5·5	14·5	34·5	38·0
Mexican Oils.										
Straight Mexican crude oil B.	0·929	at 0° C. viscous at – 15° C. nearly solid	36	58	6·0	7·5	6·5	11·5	de-comp. 49·0	—
South American Oils.										
Crude oil from Comodore Rivadavia (Argentine)	0·928	at 0° C. buttery at – 15° C. solid	102	167	1·0	2·0	6·0	18·0	de comp. 61·0	—
Indian Oils.										
Borneo Diesel engine oil	0·951	at – 17° C. very viscous but still not solid	126	144	0·0	0·0	13·0	34·5	38·5	9·1
Japanese Oils.										
Kushiwasaki residue ..	0·932	at 0° C. liquid at – 15° C. liquid	131	176	—	0·5	0·5	6·0	42·0	48·5
GROUP B.										
Lignite and Shale Products.										
Yellow oil from Gerstewitz	0·852	at 0° C. liquid at – 15° C. liquid	76	90	—	13·0	62·5	20·5	1·5	—
Schiste bitumineux (Autun)	0·88	at 0° C. very mobile at – 15° C. buttery	52	131	0·8	2·0	11·5	38·3	33·7	9·0
Scotch crude shale oil for Diesel engines	0·942	at – 11° C. solid	102	114	—	3·8	52·3	31·2	11·1	1·0

* Heat of combustion

FUEL TESTING LABORATORIES, ZURICH.

Properties.		Chemical Properties.									
and Water-Free Oils).		Crude Oils.				Pure Oils—i.e., Free from Water and Ash.					
		Content.				Ultimate Composition.					
Residue.	Appearance of Residue.	Water.	Ash.	Combustible.	Net Calorific Value.	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Sulphur.	Heat of Combustion.*	Asphalt Content.
%		%	%	%	Cal. per Kg.	%	%	%	%	Cal. per Kg.	%
0·7	viscous, brown	0·00	0·00	100·00	10139	86·2	12·8	0·6	0·4	10832	0·00
—	viscous	0·00	0·00	100·00	10033	86·3	12·4	1·2	0·1	10703	—
7·0	—	0·14	0·1	99·76	9922	86·6	11·7	1·4	0·3	10581	1·57
8·5	melted, partly coked	0·45	0·13	99·42	9782	86·9	11·5	1·2	0·4	10460	1·43
1·5	—	0·00	0·00	100·00	10129	86·4	12·9	0·5	0·2	10826	0·00
2·2	—	0·00	0·00	100·00	10120	86·9	12·6	0·2	0·3	10799	0·00
5·5	black, coked	traces	0·07	99·93	10095	86·8	12·3	0·4	0·5	10756	1·20
19·5	melted, partly coked	0·09	0·04	99·87	9743	84·2	11·4	0·8	3·6	10373	15·83
12·0	black, coked	0·05	0·03	99·93	9998	86·7	12·1	1·0	0·2	10661	9·60
4·9	coked	traces	0·02	99·98	9858	87·7	11·1	0·7	0·5	10455	0·77
2·5	black, coked	0·00	0·19	99·81	9968	88·0	11·6	0·2	0·2	10613	0·09
2·5	brown, fluid	0·00	0·00	100·00	10004	86·3	12·0	0·8	0·9	10633	—
4·7	sooty	0·00	0·00	100·00	9838	85·7	11·9	1·9	0·5	10483	0·00
0·6	coked, solid	traces	traces	100·00	9409	86·4	9·8	3·1	0·7	9941	0·00

= gross calorific value.

TESTS MADE BY THE SWISS FEDERAL

Kind of Fuel.	Physical					
	Crude Oils.				*Distillation Test and Water*	
	Specific Gravity at 15° C.	*State when Cold.*	*Flash Point.*	*Burning Point.*	*Light Oil 0–170° C.*	*Medium Oil 170–230° C.*
Group C.			*° C.*	*° C.*	%	%
Coal Tars.						
Coke Oven Tars.						
Dr. C. Otto and Co., Dahlhausen	1·179	at 0° C. solid, buttery at – 15° C. solid, hard	133	155	0·0	3·0
Vertical Retort Tars.						
Gas Works, Lausanne ..	1·101	at 0° C. rather viscous at – 15° C. viscous	43	76	3·0	13·0
Inclined Retort Tars.						
Gas Works, Berne ..	1·157	at 0° C. viscous at – 15° C. buttery	68	94	1·5	15·5
Group D.						
Coal Tar Distillates, Coal Tar Oils.						
Intermediate fraction tar oil, coke ovens, Dutch colliery	1·063	at 0° C. mobile at – 15° C. mobile	95	115	0·5	13·0
Creosote oil, Soc. An. de Carbonisation, Paris	1·061	at 0° C. liquid at – 15° C. liquid	90	109	0·2	29·6
Tar oil	1·022	at 0° C. mobile at – 15° C. mobile	88	108	0·0	44·5
Group E.						
Oil Gas Tar.						
Carburetted Water Gas Tar.						
Oil Gas Tar.						
Mines de Ségré	1·051	at 0° C. liquid at – 15° C. liquid	69	89	2·5	16·0
Carburetted Water Gas Tar.						
Gas Works, West Amsterdam, centrifugal tar	1·054	at 0° C. mobile at – 15° C. rather mobile	55	82	3·0	16·0
Gas Works, St. Gall ..	1·088	at 0° C. crystals separate at – 15° C. almost solid	61	83	3·3	16·5
					0–200° C.	200–250° C.
Group F.						
Vegetable Oils.						
Arachis oil	0·916	at 0° C. solid	310	348	—	—
Rape oil	0·917	at 0° C. mobile at – 15° C. almost solid	300	345	—	5·8
Castor oil	0·962	at 0° C. very viscous at – 15° C. nearly solid	290	320	—	29·0

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* Heat of combustion

FUEL TESTING LABORATORIES, ZURICH.

PROPERTIES.				CHEMICAL PROPERTIES.										
Calculated for Ash Free Oils.				*Crude Oils.*				*Calculated for Ash and Water-Free Oils.*						
				Content.				*Ultimate Composition.*						
Heavy Oil 230–270° *C.*	*Anthracene Oil* 270–350° *C.*	*Residua (Pitch).*	*Coke Content of Pitch.*	*Water.*	*Ash.*	*Combustible Matter.*	*Net Calorific Value.*	*Carbon.*	*Hydrogen.*	*Oxygen and Nitrogen.*	*Sulphur.*	*Heat of Combustion.**	*Free Carbon Content.*	*Naphthalene Content.*
%	%	%	%	%	%	%	*Cal. per Kg.*	%	%	%	%	*Cal. per Kg.*	%	%
8·5	24·5	64·0	22·0	2·22	0·10	97·68	8615	91·1	5·3	2·8	0·8	9120	4·1	2·3
13·0	20·0	51·0	20·0	1·11	0·01	98·88	8757	88·8	6·6	4·1	0·5	9225	3·4	1·0
11·5	20·5	51·0	40·0	1·11	0·02	98·87	8671	89·9	6·0	3·6	0·5	9096	14·0	3·3
29·0	46·0	11·5	2·1	0·18	traces	99·82	8981	89·8	6·6	2·9	0·7	9355	traces	—
31·1	34·5	4·6	1·5	0·26	0·01	99·73	8872	88·9	6·5	3·9	0·7	9250	traces	—
27·5	26·0	2·0	0·9	0·87	0·03	99·10	8874	87·5	7·5	4·5	0·5	9363	traces	8·5
19·0	31·0	31·5	—	0·32	0·05	99·63	9312	91·8	7·1	0·5	0·6	9733	traces	traces
24·5	28·5	28·0	33·0	0·59	0·07	99·34	9261	92·2	6·8	0·4	0·6	9695	traces	1·9
14·9	19·3	46·0	27·0	9·33	0·08	90·59	8174	92·0	6·3	1·0	0·7	9425	4·0	0·7
250–300° C	300–350° C.													
13·0	82·0	5·0	—	traces	traces	100·00	8866	77·3	11·8	10·8	0·1	9500	—	—
63·7	—	30·5	—	—	traces	100·00	8790	76·8	11·9	11·3	—	—	—	—
—	—	71·0	—	0·63	—	99·37	8257	72·9	11·2	15·3	—	—	—	—

= gross calorific value.

3. OUTLOOK AS TO THE FUTURE SUPPLY OF FUEL OILS FOR DIESEL ENGINES.

It has often been asked if the supply of Diesel engine fuel will sooner or later prove inadequate, either because of suitable oils not being produced in sufficient quantities, or because of these oils being claimed by other industries, and therefore having their prices raised to a prohibitive figure. When reviewing this question we shall consider the two principal classes of fuels at present in use—namely, the petroleum oils and the coal tar oils—neglecting other fuels, such as lignite tars and shale oils, oil gas tars, and vegetable oils, of which but small quantities are produced.

THE PRODUCTION OF DIESEL FUEL OILS.

Petroleum.—The so-called fuel oils constitute the bulk of Diesel engine fuels. Varieties of kerosenes which are suitable for this purpose may be left out of consideration at present. The following statistics will therefore be restricted to the total production of fuel oils.

It will be found that statistics on the output of petroleum products are anything but accurate. For many oil fields no data are available, and certain other districts often make it a practice to understate their output in order to escape undesirable competition. The following figures, taken from published statistics, can therefore be safely regarded as being below the actual amounts.

While these data on the production of crude petroleum are sufficient, precise information about the products obtained by various processes of distillation, etc., is entirely lacking. We must therefore have recourse to the statistics of certain districts, and endeavour to gain from these sources a general idea of the fuel oil production as a whole.

Among the crude oils we only find certain kinds which lend themselves to complete technical treatment—that is, to the production of petrol, kerosene, and lubricating oil. The immense quantities of crudes which show high percentages of sulphur compounds and asphalt are only suitable for the production of benzines (5 to 10 per cent. of the weight of crude), while the residue cannot be used otherwise than as fuel oil. Yet the first-named products are not always entirely extracted, but a great part of them goes on to the market in the fuel oils.

Official statistics of the Baku oil district show that there were exported in 1912—

	*Poods.**	*Per Cent.*
Petrols	1,861,000	0·50
Illuminating oils	85,119,000	23·00
Lubricating oils	19,408,000	5·25
Solar oil	5,278,000	1·44
Mazut	206,224,000	56·11
Crude naphtha	50,434,000	13·70
Total	368,324,000	100·00

If we assume that half the crude naphtha exported is used as fuel oil, and if the solar oil be included in this category, we have then a total of 64 per cent. of the whole as fuel oil.

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* 1 pood=36·13 English pounds.

The exports of Roumania in 1911 were as follows (according to the *Moniteur du Petrole Roumain*):

	Tons.	*Per Cent.*
Petrol	260,653 ..	18·8
Illuminating oil	312,711 ..	22·5
Lubricating oil	24,703 ..	1·8
Residuum	783,136 ..	56·9
Total	1,381,203 ..	100·00

If the Roumanian home consumption were added, the percentage of fuel oil would in all probability be considerably greater.

In America it is chiefly the eastern oil fields which give rich oils; the fields of the south-west, which, by the way, show an enormous development, yield in preponderating proportion fuel oils.

The total output of the United States of America was—

	In 1913.	*In* 1916.
	Barrels.	Barrels.
Total	220,449,000	300,767,000

Of this total the following principal fuel oil districts have supplied—

	In 1913.	*In* 1916.
	Barrels.	Barrels.
California	81,134,000	90,951,000
Oklahoma	56,069,000	107,071,000
Texas	9,526,000	27,644,000
Total	146,729,000	225,666,000
Proportion	66 per cent.	73 per cent.

It must be remembered that great quantities of the rich American oils are worked up into fuel oil, and it may safely be assumed that this part is not less than 50 per cent., taking into account the great extent to which liquid fuel is used in America.

Mexico supplies mainly fuel oils. In the future the output of this country is most likely to increase enormously, and this view is justified by the fact that to-day only about 2 per cent. of the total estimated oil fields there are worked. Moreover, conditions there seem to be very favourable, as the wells generally turn out to be powerful gushers. To give an example, the well Cerro Azul No. 4 yielded, at the beginning, the enormous quantity of over 200,000 barrels per day, which figure may be compared with that for the world's consumption of Diesel engine fuels in 1918, which was but 20,000 barrels per day.

CRUDE OIL PRODUCTION OF MEXICO.

	Barrels.
1911	14,051,000
1915	32,910,000
1916	39,817,000
1917	55,293,000

The fuel oil production of the South American, Asiatic, and other oil fields may be assumed to be at least 75 per cent. of the respective crude oil production, but we shall for safety's sake take it as only 65 per cent., a figure which is approximately in accordance with the Russian conditions.

The world's production of petroleum has increased since 1900 by about 2½ million tons every year, and this increase of production will, without doubt, still long continue, even if no new oil fields should be opened up. The figures in the following table refer to the output for the year 1913; at the present date they would have to be increased considerably. The United States Geological Survey, Washington, gives in *Press Bulletin* 382 of September 30, 1918, an estimate of the world's gross production for the year 1917 at 68,000,595 tons.

THE WORLD'S PRODUCTION OF FUEL OILS IN 1913.

	Crude Oil Production in Tons.	*Fuel Oil Production.*	
		Per Cent.	*In Tons.*
United States of America:			
Central and Eastern States	11,000,000	50	5,500,000
South-Western States ..	21,300,000	80	17,000,000
Russia	9,250,000	64	5,900,000
Roumania	1,880,000	55	1,060,000
Mexico	3,000,000	90	2,700,000
Other Countries	4,370,000	65	2,840,000
Total	50,800,000		35,000,000

These 35 million tons of fuel oil correspond to about 70 per cent. of the world's production of petroleum. In coming years no doubt the increased demand for petrol will influence in some degree the quantities of fuel oil produced, as a certain quantity of medium and heavy distillates will be taken for cracking, so that the fuel oil production may be set back to some extent. The cracking process is based on the fact that heavy hydrocarbons, when subjected to prolonged heating, give off various light oils and permanent gases. It is possible to produce considerable quantities of light petroleum and petrols in this manner.

Tar Oils.—Unfortunately, the statistical information on the production of tar is extremely meagre, so that the figures relating to it must be taken with great caution. The tar oil industry of to-day is expanding, and is far from having attained full development. We must therefore consider less the present state than the possibilities of production in the future. The increasing tendency to decompose coal into such valuable products as coke, tar, and ammonia, instead of burning it directly, and thus to attain the most economic exploitation, is bound to have a great influence on the production. It may be expected that, in course of time, at least half the total coal output will be worked up on these economic lines. At present we are still considerably distant from these conditions.

Rau gives an estimate ("Stahl u. Eisen," 1910, p. 1296) for the year 1909, according to which the percentage of the total coal output which was coked was—

	Per Cent.
United States of America	13
England	18
Belgium	20
Germany	24

On an average it may be assumed that 100 tons of coal give about 2 tons of tar oil, and assuming that at any rate in the immediate future not more than 30 per cent. of the total coal output will be worked into coke, the tar oil production will come out at 0·6 per cent. of the coal output.

THE WORLD'S PRODUCTION OF COAL.

Year	1872.	1882.	1895.	1900.	1905.	1910.	1912.
Production in millions of tons	256	319	580	770	925	1,110	1,200

On the basis of a world's output of 1,200 million tons of coal, of which 30 per cent. would be worked into coke, 7·2 million tons of tar oil would be obtained. Of this quantity about 25 per cent. might be consumed for creosoting and other industrial purposes, so that about 5·5 million tons of fuel oil would be available. The present high price of coal, however, makes it most probable that the coking process, with its concomitant tar oil production, will claim in the future a much greater proportion of the coal output.

THE CONSUMPTION OF DIESEL ENGINE FUEL.

Let us assume an average consumption figure of 0·5 tons petroleum fuel oil, or 0·56 tons of coal tar oil, for every nominal Diesel horse power per year, corresponding to 3,600 working hours at 70 per cent. load factor, and let us put down the aggregate power of Diesel engines in existence up to 1918 at 2,000,000. If we further assume that 500,000 horse power are added every year (which is an outside figure), then the consumption figures for the next few years work out as follows:

Year	1920.	1925.	1930.	1935.	1940.
Million horse power ..	3	5·5	8	10·5	13
Fuel consumption:					
Millions of tons petroleum; or,	1·5	2·75	4	5·25	6·5
Millions of tons tar oils.	1·68	3·08	4·5	5·7	7·3

Against this some 40 to 50 million tons obtained from petroleum are available, and in addition we may reckon on a quantity of tar oil which is alone sufficient to cover the whole Diesel requirements, if only moderate progress be made in the coking industry. The assumption made above, that all power oils are suitable for Diesel engines, is subject to certain exceptions, as oils with heavy ash content should be used in Diesel engines only if the impurities which cause serious abrasion are first removed. But at present this improvement in quality can only be done by distillation, which entails certain expenses and loss of heat, and naturally raises the price above that of crude fuel oils.

The Question of Prices.—By far the greater part of petroleum fuel oils, and also of tar oils, is used for furnace firing (principally for boiler firing), and this will probably long remain their chief use, because, apart from Diesel engine use and the possibility of working up into lubricating oils, no other considerable field for their utilisation exists. From this it follows that the price of these oils will always be determined by the current coal prices. A material increase in oil prices disproportionate to a rise in coal prices would immediately cause a return to coal firing and a corresponding diminution of oil firing.

When examining as to whether Diesel engines risk being deprived of their fuel owing to its being monopolised by other industries, the following facts may be taken into consideration: 1 horse power hour requires 0·6 to 1·5 kilograms of petroleum fuel oil, or 0·7 to 1·7 kilograms of tar oil, when the oil is burned in a boiler furnace. But, on the other hand, 1 horse power hour requires 0·19 to 0·22 kilograms of petroleum fuel oil, or 0·22 to 0·25 kilograms of tar oil, when the oil is burned in Diesel engines.

Thus the fuel oil consumption per steam engine horse power hour works out at three to eight times as much as per Diesel horse power hour.

It is therefore obvious that an increase in fuel prices affects the Diesel engine much less than it does the oil-fired steam boiler plant.

Summary.—Fuel for Diesel engines will be abundant for a good many years to come. The fuel prices will always move in a certain relationship with the coal prices, and even if prices should turn to the disadvantage of Diesel engine users, this would be more than counterbalanced by the superior economy of the Diesel engine.

II.—LUBRICATING OILS.

PROPERTIES, CLASSIFICATION, AND SPECIFICATIONS.

MODERN Diesel engines are lubricated exclusively with mineral oils obtained from the heavy components of the petroleum crude oils. Certain crude oils from the central and eastern fields of the United States, and the Russian oils, are, from their composition, especially suitable for the production of high grade lubricating oils. The degree of care bestowed on the refining process is of the greatest importance, and repeated fractionating and chemical treatment are resorted to in order to eliminate all unsuitable and especially harmful components.

Lubricating oils of good quality answer to the following requirements:

The oil must be free from impurities such as acids, alkalies, resins (the resin content must never exceed 1 per cent.), water, and solid impurities. The latter often come from the barrels used in transport.

The oil, when exposed to the air, should not suffer appreciable change or decomposition even when stored for a long time. Special importance must be attached to the condition that no resinification takes place. Chance mixing with water must not produce viscous emulsions. The possibility must always be reckoned with that leaky cooling water pipes may allow small quantities of water to get into the oil.

Cylinder lubricating oils should be highly heat-resisting, and when vaporised should leave but small quantities of pitchy or resinous residues. It is not, however, the laboratory test that can be looked upon as finally decisive, but the behaviour of the oil in actual continuous service. During slow vaporisation in an open crucible decomposition sets in at high temperatures. On the other hand, the lubricant of the Diesel engine cylinder is exposed to the direct action of the hot combustion gases during only a small part of the piston stroke, while during the rest of the stroke heat is carried away by the cooled walls of the cylinder. The vaporisation residues will therefore be of quite a different nature, as the conditions prevailing in the cylinder are totally different from those of the crucible test.

When judging as to the suitability of lubricating oils for any particular employment, the following properties must also be taken into consideration:

Flash Point and Burning Point.—These both give some measure of the heat-resisting properties of cylinder lubricating oils. High flash points and burning points indicate, in general, good quality and careful refining.

Viscosity.—Thin oils should be exclusively used in cold-running and lightly loaded bearings, while thicker kinds of oil are required for high temperatures and heavier loads.

Appearance.—Well refined oils, viewed in a test tube, must not appear cloudy. The colour itself is no reliable guide as to quality. Light oils are generally of light yellow to reddish colour, heavy oils of dark red, red-brown, to dark brown colour. American oils have mostly a green fluorescence, Russian oils blue fluorescence.

Behaviour in the Cold.—Cylinder oils, when used in cold engine rooms, are often so viscous that insufficient quantities pass through the drop-feed devices, and in these cases preheating arrangements must be provided, otherwise running troubles will be unavoidable.

Specific Gravity.—This is no criterion of quality, and can be left out of consideration.

The refined, pure, mineral lubricating oils on the market may be classed in five groups as follows:

	Flash Point (Open Test).	*Burning Point.*	*Viscosity at 50° C.*
	Degrees Centigrade.	Degrees Centigrade.	Engler Degrees.
1. Spindle oils	150 to 170	180 to 200	1·5 to 3
2. Light machine oils ..	170 to 190	200 to 225	3 to 6
3. Heavy machine oils ..	190 to 230	225 to 270	6 to 15
4. Cylinder lubricating oils ..	230 to 300	270 to 340	15 to 40
5. Lubricating oils for superheated steam.	over 300	over 340	40 to 70

Each of these groups comprises a large number of oils, presenting a great variety of choice within the limit values of flash point, burning point, and viscosity. The refrigerating machine lubricating oils belong to the class of spindle oils, but must in addition answer to the condition that they shall not congeal above -20° C. The so-called black bearing oils (railway wagon axle grease) belong, as to flash point requirements, to the spindle oils, but possess the high viscosity of the heavy bearing oils. They are but incompletely or not at all refined, and are of low value for engine lubrication.

Spindle Oils.—These are out of the question for use in Diesel engines.

Light Machine Oils.—These are only suitable for the bearings of small engines (under 30 horse power per cylinder).

Heavy Machine Oils.—These oils are suitable for the bearings of small and medium size engines (up to 60 horse power per cylinder). Engines working at high temperatures (in the Tropics, hot engine room, warm circulating water, high load) should be lubricated with heavy oils.

Cylinder Lubricating Oils.—The working and compressor cylinders of large engines must be lubricated by the so-called cylinder oils. The higher the working temperature, the higher the viscosity and flash point of the oil must be. Curiously enough, one often hears the view expressed that thinner oils are better for cylinder lubrication, because they are burned at the temperature of the cylinder nearly completely, and leave only insignificant quantities of residue. It cannot be denied that sometimes a first-class oil which is fairly heat-resisting but thin, will, under certain conditions, be equal or even superior to a more viscous oil of inferior quality. As far as records are to hand, thick oils of good quality have given no trouble in very large engines. On the contrary, they have the advantage of keeping the piston tighter and reducing the oil consumption in comparison with oils of lower viscosity.

Cylinder Oils for Superheated Steam.—These may be employed where suitable cylinder oils are not obtainable.

DIESEL ENGINE LUBRICATING OILS FOR AVERAGE RUNNING CONDITIONS.

	Flash Point (Open Test).		*Burning Point.*		*Viscosity. at 50° C.*
	Degrees Cent.	Degrees Fahr.	Degrees Cent.	Degrees Fahr.	Engler Degrees.
Bearing lubricating oils for engines below 30 horse power per cylinder.	170	338	200	392	4 to 5
Bearing lubricating oils for medium and large size engines, and for engine and compressor cylinders up to 60 horse power per cylinder.	200	392	235	455	6 to 8
Lubricating oils for engine and compressor cylinders of largest power.	280	536	320	608	20 to 25

All oils should be filtered before use.

THE LOSS OF POWER BY FRICTION.

It is well known that heat is generated wherever frictional contact of machine parts takes place, the sliding or rubbing parts themselves, and also their surroundings, being heated. This clearly indicates that a certain portion of energy is lost by friction and dissipated in the form of heat. It might be thought that the heat continuously produced by friction in running machinery would accumulate in such a manner that dangerous temperatures would be reached, resulting in a breakdown, but experience has shown that temperatures only rise to certain values and then remain nearly stationary. This may be explained as follows:

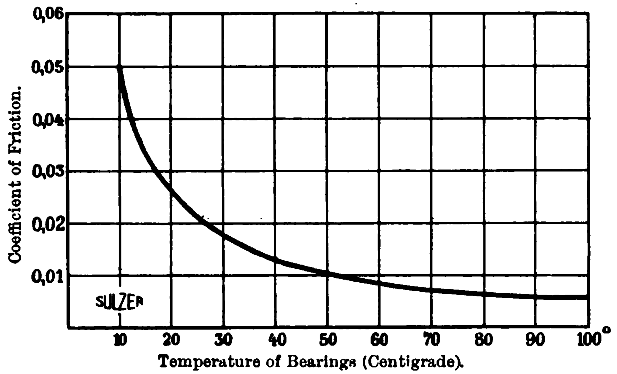


FIG. 11.—CURVE SHOWING FRICTION ON BEARINGS PER UNIT OF AREA.

(Pressure=3 kilogrammes per square centimetre, peripheral speed = 3 metres per second.)

Some of the friction heat is automatically and continuously carried away by the adjoining metal parts, foundations, brickwork, etc. Most of it, however, is dissipated into the air of the engine room, as the hot parts of the engine radiate heat in the same way as the radiators of a hot water heating system. This explains why the temperature cannot exceed a certain value.

A second factor which counteracts unlimited raising of the temperature is the singular variation of the coefficients of friction. The term "coefficient of friction" indicates the amount of frictional resistance measured in pounds per 1 pound load on the area of contact, and furnishes a direct measure for the loss of power by friction. According to circumstances this coefficient varies between 0·1 and 0·005, and depends on the shape and dimensions of the moving surfaces, on the load per unit of area, and on the nature of the surfaces and metals. Further factors are the method of lubrication and the quantity of oil which passes between the rubbing faces. The two following points are of particular importance:

1. *The Viscosity of the Oil.*—Thin oils raise the friction coefficient, because much of the oil is squeezed out from between the rubbing surfaces. Excessively viscous oils also give a higher coefficient, this being due to what is called internal friction, caused by their greater viscosity.

2. *The Coefficient of Friction is higher at low temperatures; it decreases considerably when the temperature rises, and attains its minimum value at about* 100° *C.*

It is mainly due to this fact that the heating due to friction in the moving parts of an engine does not generally exceed a certain limit, and this leads to the inference that it is desirable to maintain a high temperature in the engine parts. This especially applies to engines in which the heat generated by friction is artificially carried away—for instance, by circulating water (water-cooled cross-head slides and bearings, and the oil cooling with forced lubricating systems). In such cases it is undesirable to lower the temperature of the oil too much, as the coefficient of friction would thereby be increased. Similar conditions prevail in naturally cooled shafting bearings, in which low temperatures are likewise to be avoided. It is generally known that lines of shafting run more easily during the warmer months of the year, and that the starting up of cold shafting and machinery, after having been shut down during holidays, absorbs a considerable amount of extra power until normal conditions of temperature are reached. This is often evident during several hours in the overloading of the prime mover. It would, however, be a mistake to suppose that everything depends on the absolute temperature of the oil, for every bearing which is too heavily loaded, and which therefore runs hot, would answer to this condition. The minimum frictional loss is only attained when the difference between the temperature of the bearing and that of the room is a minimum—in other words, when the quantity of friction heat to be carried away is cut down to the minimum.

Frictional losses may be reduced by carefully selecting the most suitable quality of oil for each individual case, and it may be taken as a rule that *the most suitable lubricating oil is that which gives the lowest increase of temperature in the bearing.*

When making trials of lubricating oils, it is important to take not only the temperature of the bearing itself, but also, at the same time, the temperature of the room.

Bearings which are exposed to the weather should, in the cold season, be supplied with an oil which possesses some 1 to 3 Engler degrees lower viscosity at 50° C. than the " summer oil."

THE PURIFICATION OF USED OILS.

Oils which have been in use for some weeks or months generally become gradually contaminated to such an extent that their further use would prove disadvantageous. The impurities present are principally water, dust of every kind, sand carried in by the wind, and especially fine particles of metal. It may easily be imagined that such a lubricating oil has little lubricating property left, and, besides the loss of power by friction, must cause an abnormal amount of wear and tear in the moving parts.

Generally the oil of shafting bearings is never completely drained off; all that is done is to add from time to time a certain quantity of oil to replace that lost by evaporation or otherwise. Such careless practice may have been excusable when used oils were considered to be lost beyond recovery, but to-day there are efficient apparatus by which they may be purified and again rendered serviceable. Bearings of shafting should be completely drained off at least once every twelve months, and filled with fresh oil.

It is essential that the bearings should be thoroughly cleaned and then carefully watched when first running with the fresh oil. The oil in use in engine bearings should likewise be completely drained off from time to time (every eight or twelve months, according to circumstances). The lubricating system of engines running on poor fuels (containing pitch or asphalt) should be emptied and

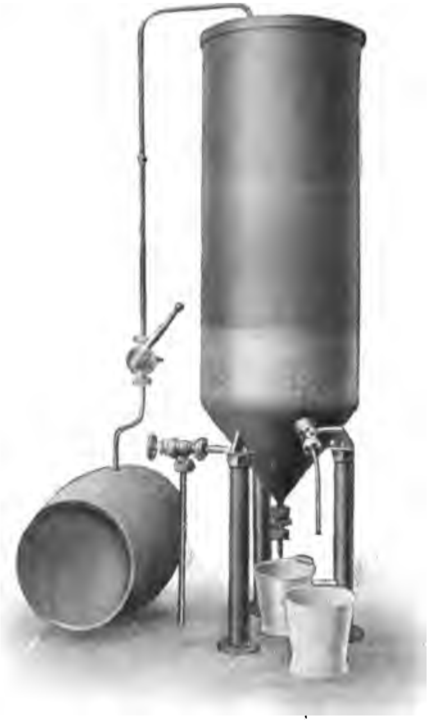


FIG. 12.—A SULZER STEAM PURIFYING APPARATUS FOR LUBRICATING OILS.

refilled more frequently, as the lubricant becomes contaminated with fuel oil. Unfortunately, such impurities cannot be extracted by the usual methods. Such deteriorated lubricants cannot be regenerated, and should not be used again except in rough bearings or as fuel.

III.—TESTING OF FUEL AND LUBRICATING OILS.

THE accurate testing of these oils can only be conducted in specially equipped laboratories. The determination of calorific value, sulphur, and carbon content, and the tests for resin and acid in lubricating oils, all demand thorough professional knowledge and special experience in such work. Tests of importance should always be carried out by an expert chemist. In ordinary cases, the general data supplied by the oil merchant will be sufficient. In order to check these, or to make complete tests if no data are obtainable, the methods explained in this chapter should be adopted. The following remarks refer to both fuel and lubricating oil testing.

Sampling.—The sample should truly represent the average quality of the oil to be tested.

The water, sand, asphalt, or other impurities present in oil become partially separated during storing, and accumulate in the uppermost layers or at the bottom of the tank according to their specific gravity. It follows that samples should be taken from various levels. For this reason the sample should be taken by means of a tube open at both ends. The sampling tube should be very slowly inserted. The lower end is provided with a device for closing it, such as a leather valve or a stopper, which is kept open while the tube is being lowered, and closed as soon as the tube has reached the level desired (Fig. 13).

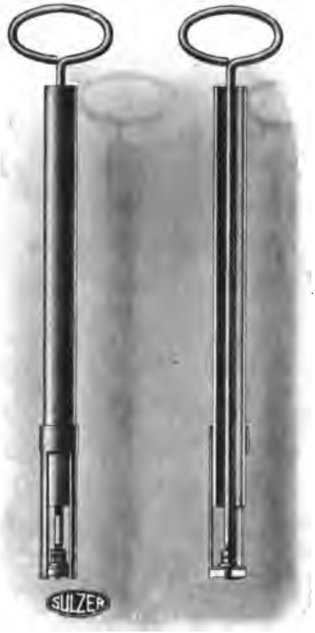


FIG. 13.—SAMPLING TUBE FOR TESTING OILS.

Fig. 14 illustrates a simpler instrument, consisting of a $\frac{1}{2}$ to $\frac{3}{4}$ inch glass (or iron) tube open at both ends. It is slowly lowered into the oil, and then the thumb is placed on the upper end and the tube carefully withdrawn. Part of the contents runs out when it is raised; but this could be avoided by providing the lower end with a contraction. The tube should not be longer than absolutely necessary, because the air above the oil column expands and allows some of the oil to run out.

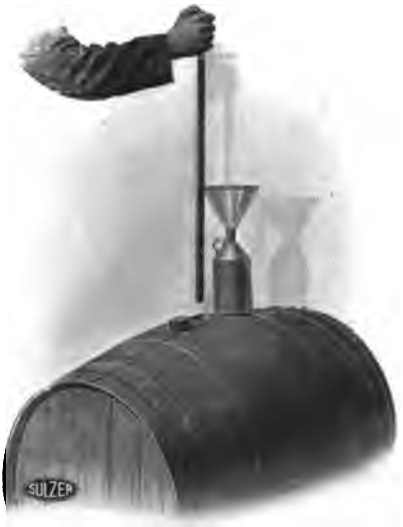


FIG. 14.—SAMPLING OIL WITH GLASS TUBE.

Lubricating oils are generally quite homogeneous, so that the sampling does not require any special precautions—for instance, it may be done simply by a ladle.

At least 1 litre should be taken in sampling fuel oils, or ½ litre in the case of a lubricating oil; this should then be put into a thoroughly clean and dry glass or tin vessel. It is advisable immediately to close the sample vessel airtight when an accurate fuel test is to be made.

It is desirable to label the sample exactly with name of merchant, date of arrival, trade name or brand, country of origin (only with fuel oils), date of sampling and number of railway wagon.

Specific Gravity.—Fig. 15 shows an instrument called an hydrometer. When immersed in the liquid which is to be tested it floats at a certain depth. The stem of the instrument is provided with a graduated scale, and the number on the scale which coincides with the surface of the liquid directly indicates the specific gravity. In using this instrument it must not be overlooked that the oil clings to the stem and is drawn up a little. The reading must not be taken at this higher point, but exactly at the height of the level of the oil in the containing vessel. There are sometimes very opaque oils with which the reading can only be made at the raised oil level, and a certain allowance for the difference must be made (added). All oils for Diesel engines have specific gravities between 0·8 and 1·2, and two hydrometers are generally used, one for the lighter and one for the heavier oils. It frequently occurs that very small samples only are available for testing, so it is advisable to keep, in addition to the standard instruments, a set of miniature hydrometers. Hydrometers with Baumé scale should not be used, for there are several varieties of this system on the market, and they often differ so considerably from each other that mistakes may be made in using them. In cases where no hydrometer is available the following method may prove useful:

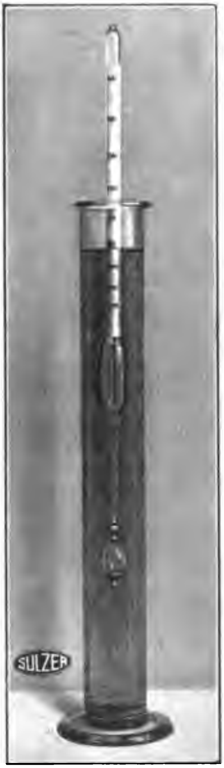


FIG. 15.—HYDROMETER (FOR MEASURING SPECIFIC GRAVITY).

Place an empty bottle of 100 to 200 c.c. content on a balance and weigh it; then fill it completely with water and weigh it again. The difference between the two weights gives the weight of the water. Now empty the bottle, dry it thoroughly, and fill it with the oil to be tested and weigh again. Divide the net weight of oil by the net weight of water, and the result gives the specific gravity.

By conventional practice all these tests should be made at the standard temperature of 15° C. Any deviation from this temperature will result in an incorrect figure for specific gravity, temperatures above 15° C. giving too low values, while under 15° C. too high figures are obtained. The annexed table gives approximate figures for the correction of specific gravities taken at other temperatures, the value shown in the table to be added or subtracted respectively if the testing temperature be higher or lower than 15° C.

Temperature in Degrees Centigrade.	*Coefficient for Correction.*	
	To be Deducted.	*To be Added.*
10	0·0035	—
12	0·0021	—
14	0·0007	—
15	—	—
16	—	0·0007
18	—	0·0021
20	—	0·0035
22	—	0·0049
24	—	0·0063
26	—	0·0077
28	—	0·0091
30	—	0·0105

Example.—The temperature of a sample of gas oil is 26° C., and the hydrometer gives a specific gravity of 0·87. According to the above table 0·0077 must be added, making the real specific gravity at standard temperatures $= 0{\cdot}87 + 0{\cdot}0077 = 0{\cdot}8777$.

Another Example.—The temperature of the oil sample is 12° C., and the hydrometer indicates 0·88; the correct specific gravity then works out: $0{\cdot}88 - 0{\cdot}0021 = 0{\cdot}8779$.

Determination of Flash Point.—A porcelain or metal crucible, 1½ or 2 inches diameter and 1½ to 2 inches deep (Fig. 16), is filled three-quarters full with the oil to be tested, and then slowly heated. On

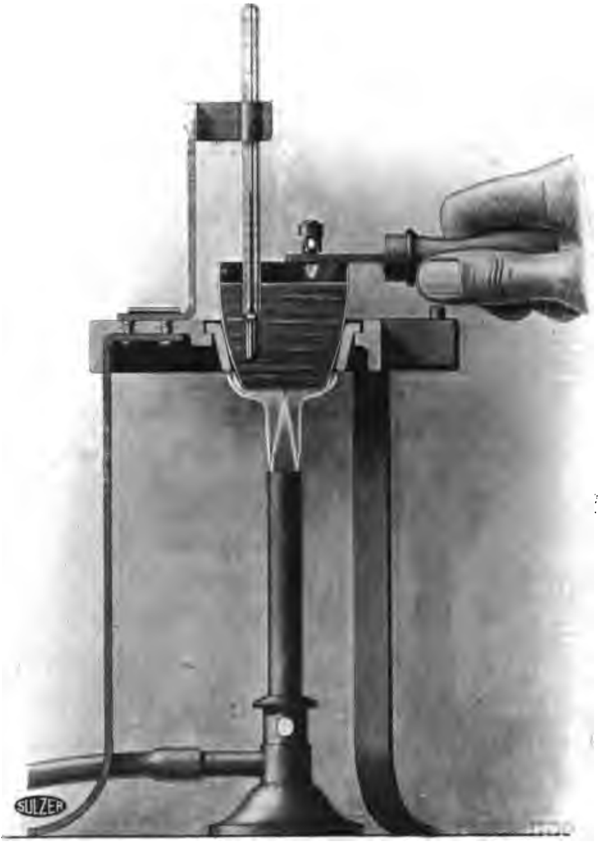


FIG. 16.—TESTING FOR FLASH POINT.

applying a small flame at intervals to the surface of the oil, little repeated flashes of flame will be found at a certain temperature to run over the surface of the oil. This is caused by the ignition of the vapours disengaged from the oil. This temperature is called the flash point of the oil. If the temperature is further increased, we eventually arrive at a point where the flames on the surface of the oil no longer go out, but continue to burn evenly. This is the burning point, which, with light oils, lies 5° C. to 20° C. above the flash point; with heavier kinds up to 50° C. higher. This is also known as the fire test. The burning temperature is somewhat dependent upon the design of the testing apparatus, and the open crucible arrangement gives a higher value than closed instruments—*i.e.*, those in which the crucible is covered with a lid. Nowadays either the Pensky-Martens or the Gray closed type apparatus is generally used for accurate tests.

There are some kinds of liquid fuels with flash points far below 0° C.—for instance, the petrols, with flash point down to -50° C. The thermometer must not touch the bottom of the crucible, but should be fixed so that the bulb is about $\frac{1}{4}$ to $\frac{1}{2}$ inch from the bottom. For accurate tests the heating should not be by a naked flame, but in a sand bath. The most convenient form of ignition flame is a small gas jet; failing this, a small kerosene torch consisting of a round wick fixed in a handle may be employed. The ignition flame must not be applied continuously, but only from time to time, say at intervals of 5° C., and a distance of $\frac{1}{8}$ inch between the flame and the oil surface should be kept. Needless to say, the crucible must be filled afresh for repeated tests. The heating may be effected by means of a spirit lamp, but on no account by a benzine lamp.

Viscosity.—The term viscosity or degree of fluidity in degrees Engler indicates how much more slowly a certain kind of oil flows out of an orifice than the same quantity of water at a standard temperature of 20° C. This definition only refers to a certain type of apparatus designed by Engler and called the "Engler viscometer." Fig. 17 shows a viscometer of simplified design which is very suitable for testing fuel and lubricating oils, and is sufficiently accurate provided that it is handled with reasonable care. Engler's original apparatus requires a sample quantity of 250 c.c., while simplified apparatus works with only 25 c.c., and is therefore called the "one-tenth viscometer." The latter instrument is convenient, as merchants' samples are as a rule only small. The apparatus consists of a vessel containing water, *a*, heated by a gas or spirit flame, an oil cup, *b*, with outlet orifice, *c*, which may be closed by a plug, *d*, and of a graduated measuring cylinder, *f*. The apparatus is levelled, and the vessel *a* filled with water; a thermometer, *g*, is placed in the vessel *b*, the orifice closed by the plug *d*, and *b* filled with oil up to the level of the indicator *h*. While filling, the plug should be slightly raised until a drop becomes visible clinging to the outlet underneath. Then the temperature of the oil is slowly raised by heating the water bath till it reaches the desired point (for instance, 50° C.), and, when this is attained, the plug *d* is quickly raised so that the oil runs out into the measuring cylinder. The discharge time for 20 c.c. must be recorded as accurately as possible (the best method is by a stop watch, as in Fig. 18).

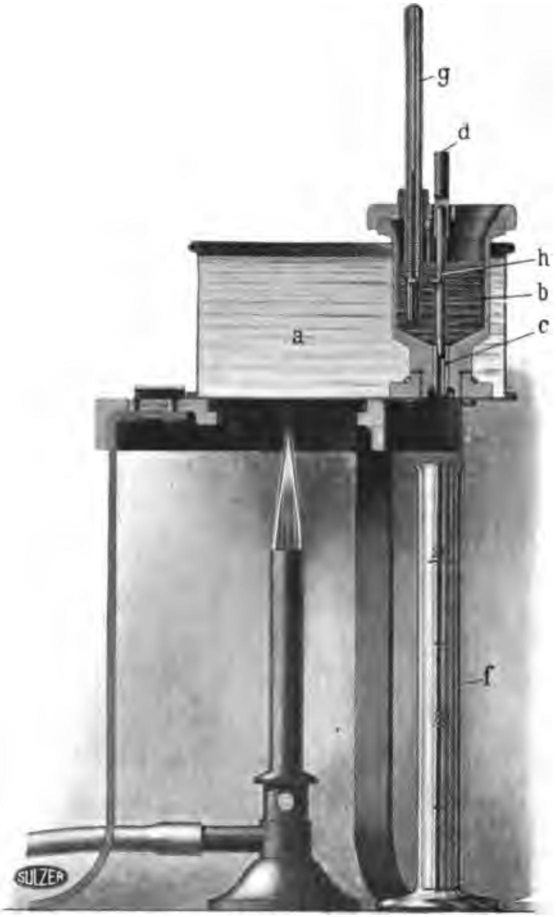


FIG. 17.—VISCOMETER.

Now divide the discharge time of the oil by that required for the same quantity of water (about 5 seconds), which is given in the working instructions for the apparatus. This value is a direct measure in Engler degrees of the viscosity of the oil tested (Fig. 18).

This apparatus, when handled with fair skill, shows deviations of 6 to 10 per cent. above or below the results obtained by the original Engler viscometer, but repeated tests may bring the error down to 3 to 5 per cent. The oil should be filtered through a fine metal gauze sieve (0·3 millimetre mesh) before being tested. The heating of the water bath must be carefully adjusted before and during the actual test in such a manner that the temperature of the oil does not vary appreciably. After the test the

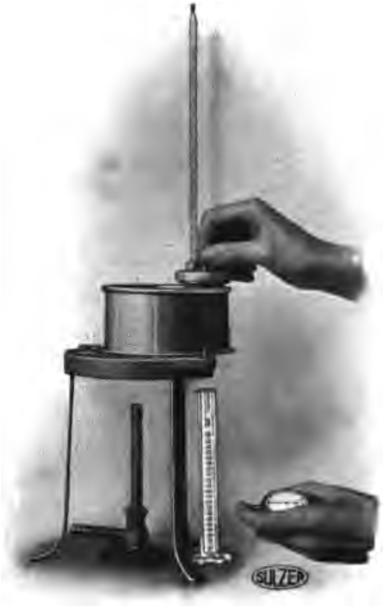


FIG. 18.—VISCOMETER (TIMING WITH STOP WATCH).

oil vessel and graduated measuring cylinder must be thoroughly cleaned, first with kerosene, and then with petrol or benzine (this must be done carefully because of the inflammability of these liquids). The viscosity of oils in the cold state should be determined at the standard temperature of 20° C. Steam engine cylinder oils must be tested at 20°, 50°, and 100° C., for which purpose the heating bath is filled with ordinary lubricating oil instead of water.

Messrs. Sulzer Bros., Winterthur, can supply the following instruments:

Flash point tester (Fig. 16).
Small Eng'er viscometer (Figs. 17 and 18).
Oil evaporator (Figs. 20 and 21).
Sulphur tester (Fig. 23).

Viscosity and Temperature.—The viscosity of an oil decreases with increase in temperature; all oils can therefore be brought, by heating, to almost any state of fluidity. Within certain limits of temperature—for instance, 20° and 100°—the variation in the viscosity of the various oils under consideration is not quite regular. When testing mineral oils one must bear in mind that wax-like components—for example, paraffin wax—give a comparatively high viscosity to the oil at the normal temperature. Such oils when heated show a more rapidly decreasing viscosity than oils which contain no such highly viscous matter.

Where the viscosity of an oil at one temperature is known, the viscosity for other temperatures not far removed may be approximately deduced. The following table is based on a standard temperature of 50° C., and for the lower temperatures two ranges of limiting values are given, between which values most of the cases fall, although exceptions may occur. The upper range refers to oils with high paraffin content, to asphaltic oils, and to raw coal tars, while the lower range applies to lubricating oils, to ordinary petroleum oils, and to vegetable oils.

TEMPERATURE IN DEGREES CENTIGRADE AND FAHRENHEIT.

20° C. 68° F.	30° C. 86° F.	40° C. 104° F.	50° C. 122° F.	60° C. 140° F.	70° C. 158° F.	80° C. 176° F.	90° C. 194° F.	100° C. 212° F.
		Viscosity (Engler Degrees).						
4·0 1·9	2·40 1·75	1·76 1·60	**1·5**	1·40	1·30	1·23	1·17	1·12
7·5 3·5	4·2 2·8	2·7 2·4	**2·0**	1·68	1·48	1·34	1·24	1·16
17·7 9·5	8·6 6·0	4·6 4·0	**3·0**	2·25	1·83	1·57	1·40	1·25
27·5 16·0	12·5 9·2	6·5 5·6	**4·0**	2·84	2·20	1·79	1·56	1·35
38·0 23·5	16·5 13·5	8·8 7·7	**5·0**	3·45	2·56	2·00	1·72	1·46
48·0 30·5	21·0 17·3	10·6 9·7	**6·0**	4·05	2·93	2·24	1·88	1·57
68·0 44·5	30·0 24·5	15·0 13·8	**8·0**	5·35	3·70	2·77	2·20	1·79
88·0 59·0	37·0 29·5	18·5 16·3	**10·0**	6·70	4·55	3·30	2·55	2·00
138·0 94·0	58·0 45·0	27·0 24·0	**15·0**	10·10	7·00	4·90	3·50	2·45
180·0 130·0	78·0 60·0	36·0 32·0	**20·0**	13·60	9·50	6·60	4·50	2·95
300·0 210·0	110·0 90·0	53·0 48·0	**30·0**	20·80	14·70	10·30	6·80	3·90
420·0 290·0	155·0 120·0	71·0 64·0	**40·0**	28·30	20·40	14·00	9·30	4·70
650·0 450·0	234·0 180·0	107·0 96·0	**60·0**	42·70	31·50	21·50	13·70	7·00
880·0 610·0	310·0 240·0	143·0 128·0	**80·0**	57·30	43·00	29·30	18·50	9·00

Viscosities of Some Fuel Oils.

	Specific Gravity at 20° C.	Viscosity in Engler Degrees.		
		Oil Temperature, 20° C.	Oil Temperature, 50° C.	Oil Temperature, 100° C.
Petroleum oils:				
Galician	0·86	1·9	1·3	1·06
	0·88	3·0	1·6	1·15
Roumanian	0·93	15·0	3·0	1·40
	0·95	50·0	7·5	1·70
		100·0	10·0	2·00
Russian	0·88	3·0	1·6	1·15
	0·95	150·0	15·0	2·50
North American	0·89	5·5	2·0	1·25
	0·89	11·0	2·5	1·40
Mexican Gas oil	0·87	2·0	1·4	1·05
Mexican Fuel oil	0·94	80·0	12·0	2·50
		300·0	28·0	4·50
Argentine	0·92	450·0	40·0	5·00
	0·94	900·0	80·0	7·00
	0·99	2,200·0	200·0	13·00
Asiatic Borneo oil	0·95	15·0	3·0	1·40
Asiatic Japanese oil	0·93	12·0	2·7	1·30
	0·96	300·0	27·0	2·50
Tars and oils from lignite and shale.	0·85	1·2	1·0	0·95
	0·95	1·5	1·2	1·00
Coal tars:				
Vertical retort tar	1·08	16·0	2·5	1·20
	1·12	30·0	3·8	1·40
Chamber oven tars	1·06	8·0	2·3	1·20
	1·09	14·0	2·5	1·20
Coke oven tars	1·15	60·0	5·0	1·40
	1·18	150·0	10·0	1·60
Inclined retort tars	1·12	30·0	4·0	1·50
	1·15	90·0	4·0	1·50
Horizontal retort tars	1·18	70·0	6·5	2·40
Coal tar oils	1·02	1·5	1·1	0·97
	1·06	1·7	1·2	1·00
	1·09	2·9	1·4	1·07
Oil-gas tars and carburetted water-gas tars.	1·07	4·0	1·8	1·20
Vegetable oils:				
Arachis oil	0·92	12·9	3·8	1·05
Palm oil	0·91	12·5	3·6	1·52
Rape oil	0·92	14·0	4·4	1·20
Castor oil	0·96	125·0	18·0	3·00

Redwood's Viscometer.—This instrument, which is much in use in England, works on the same principle as the Engler apparatus. The only difference is that the viscosity is stated in seconds, or, in other words, the viscosity is simply reckoned by the number of seconds required for the oil to run out. Redwood's instrument has been made in two sizes, the time for emptying the two instruments being in the proportion of about 10 to 1.

For the purpose of rough comparison it may be taken that—

1° Engler = 30 seconds Redwood, Size I.
1° Engler = 3 seconds Redwood, Size II.

The instrument Size I. is always used for general purposes.

Calorific Value.—A calorie is the quantity of heat necessary to raise the temperature of 1 kilogram of water 1° C. For example, if 1 kilogram of oil has a calorific value of 10,000 calories, then this can supply the heat theoretically necessary to raise the temperature of 10,000 kilograms of water 1° C., or 100 kilograms of water 100° C.

The apparatus used for determining the calorific value of fuel oils is called the "bomb calorimeter" (Fig. 19). In testing for calorific value a certain quantity (1 gramme) of fuel oil is completely burned inside a steel vessel filled with compressed oxygen. This steel bomb is enclosed in a vessel containing a measured quantity of water. By the combustion of the standard quantity of fuel heat is produced, which causes a certain rise of temperature in the surrounding water, and from this the calorific value of the fuel may be calculated.

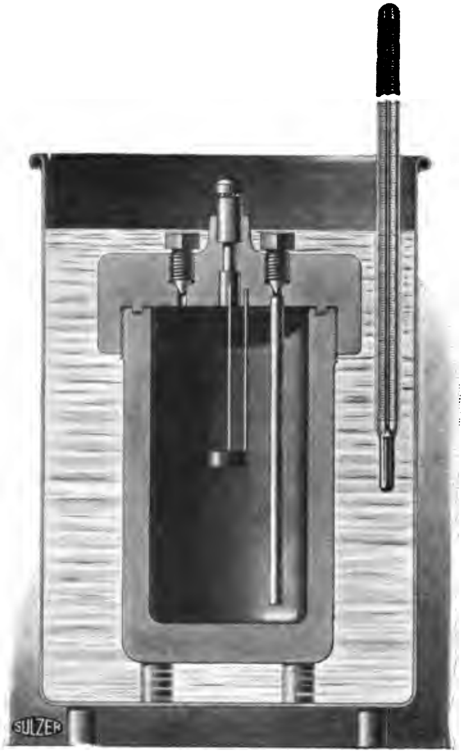


FIG. 19.—BOMB CALORIMETER.

It is necessary to distinguish between the *gross* and the *net* calorific value. The former is based upon the assumption that the latent heat of vaporisation of the water which originates from combustion of the hydrogen contained in the oil (the so-called water of combustion) is included as a part of the useful heating power of the fuel. On the other hand, the net calorific value is obtained by subtracting the latent heat of the water of combustion from the gross calorific value.

In practice the net calorific value is generally used, as the utilisation of the heat of combustion is, as a rule, never carried to below 100° C. as a final temperature. It follows that the latent heat of steam which could be set free only by condensation at a temperature below 100° C. is lost, and should therefore be subtracted from the gross calorific value.

In cases where the gross calorific value is known, the net calorific value may easily be calculated by determining from the hydrogen content the value which must be subtracted. The value to be subtracted amounts to 54 calories for every 1 per cent. by weight of hydrogen. Where the hydrogen percentage is not known, a reference to the curves on pp. 86 and 87 will allow an approximate estimate of this value being made from the specific gravity of the oil.

In the case of oils containing water, when the gross calorific value has been determined without taking into account the water content (as from a water-free sample), the net calorific value of the fuel containing water can be estimated by subtracting not only the heat of vaporisation of the water of combustion, but also another quantity of heat, as in the following table. This table gives the number of calories for every 1 per cent. of water.

Petroleum oils	106 calories.
Lignite tar oils and shale oils	104 „
Oil gas tars and carburetted water gas tars ..	98 „
Coal tar and coal tar oils	96 „
Vegetable oils	96 „

Example A.—A tar oil enumerated in the table of typical fuel analyses (pp. 44 to 47) has a specific gravity of 1·022 and a water content of 0·87 per cent. The hydrogen content was ascertained to be 7·5 per cent., and the gross calorific value of the water-free oil 9,363 calories.

The value to be subtracted for the heat of vaporisation of the water of combustion is therefore = 7·5 × 54 =405 calories, and the value to be subtracted for the water content is 0·87 × 96 =84 calories.

Therefore the total amount to be deducted is 489 calories, and the net calorific value is thus 9,363 - 489 =8,874 calories.

Example B.—In case the hydrogen content is not known, the value to be subtracted may be calculated in the following manner:

The graph on pp. 86 and 87 gives the value to be subtracted for a specific gravity of 1·022 as 410 calories, and that for the water content (see above) is 84 calories. So the total amount to be deducted is 410 + 84 =494 calories.

Therefore the net calorific value is 9,363 - 494 =8,869 calories.

In the great majority of cases but few data are to hand for the estimation of the value of a Diesel fuel oil. In such cases the commercial description will generally indicate the sort and origin of the oil. The specific gravity can be readily ascertained, and the determination of the amount of water content and ash content offers no great difficulties. It is possible even with these few data to calculate the calorific value with sufficient accuracy for practical purposes. Between the specific gravity and the calorific value of an oil of a certain class a certain relationship exists, and therefore, if the specific gravity be known, an estimate may be made of the calorific value.

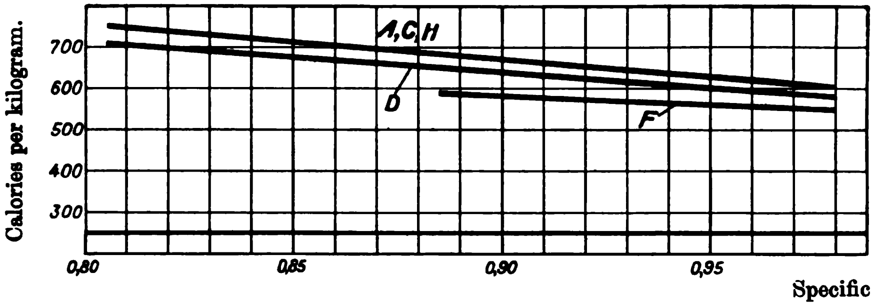
The following graphs show the relations which exist between specific gravity and net calorific value for the principal kinds of oils. The calorific values of alcohols are given on p. 40. If a vertical line be drawn from the figure for specific gravity till it cuts the respective fuel curve, the length of this line gives the approximate net calorific value, as indicated on the scale at the side of the diagram. The graphs refer to pure oils—*i.e.*, to oils free from water and ash. A deduction must therefore be made corresponding to the amount of the non-combustible components (see p. 84).

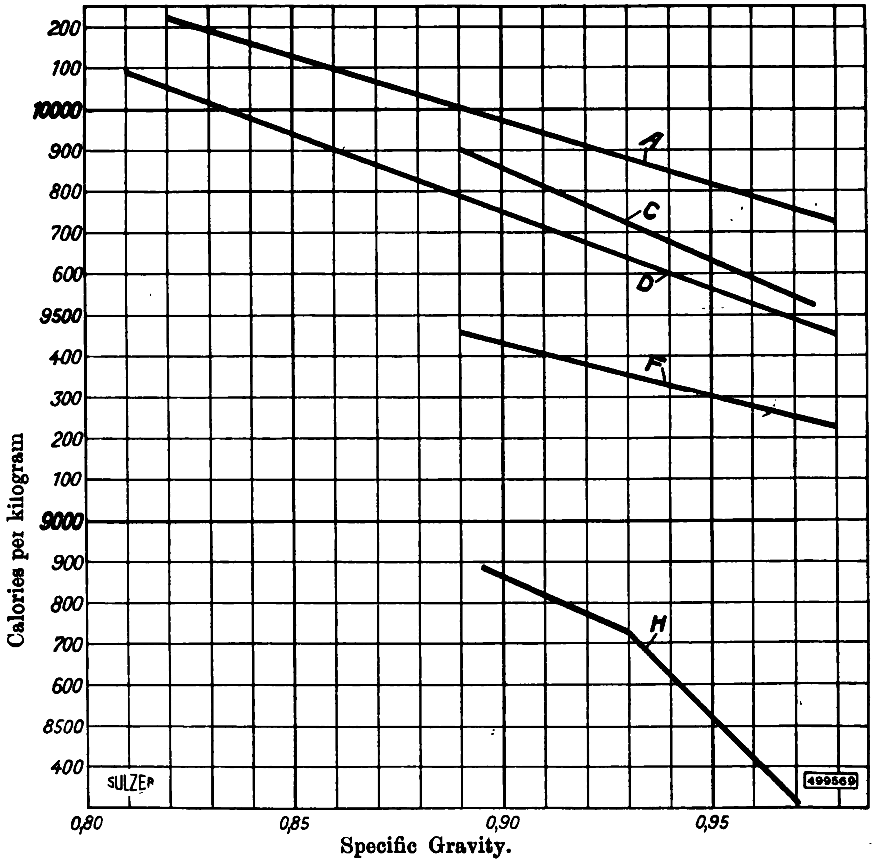
Example C.—The same tar oil as taken in examples *A* and *B*, of specific gravity 1·022, has, according to the graph (assuming it to be free from water), a net calorific value of 8,980 calories.

Subtract the value of water, which is 84 calories; then the net calorific value is 8,896 calories.

HEAT OF VAPORISATION OF

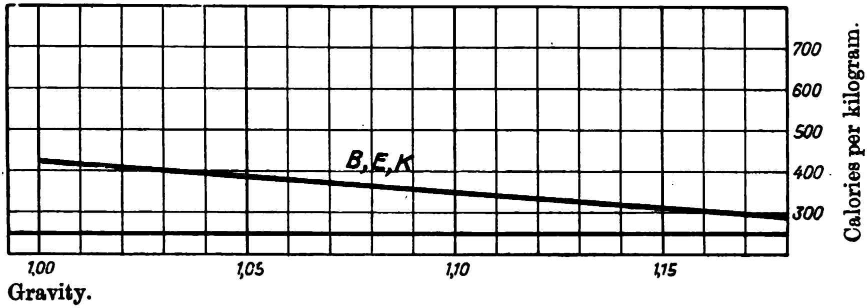
A.C.H. Petroleum and vegetable oils.
D. Lignite tar and shale oils.
F. Bohemian lignite tars.





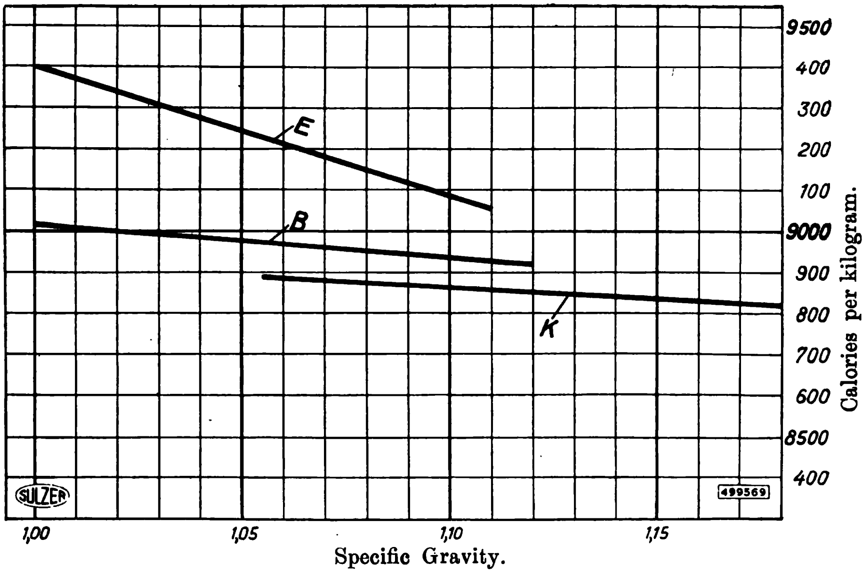
WATER OF COMBUSTION.

B.E.K. Coal tars and tar oils, and oil gas and carburetted water gas tars.



NET CALORIFIC VALUE OF WATER-FREE OILS.

A. Petroleum.
C. Mexican and Californian oils.
D. Lignite tar and shale oils.
F. Bohemian lignite tars.
H. Vegetable oils.
E. Oil gas and carburetted water gas tars.
B. Coal tar oils.
K. Coal tars.



The two foregoing diagrams of curves have been compiled from a publication on the testing of Diesel fuels by Messrs. Constam and Schläpfer, Directors of the Federal Fuel Testing Institution at Zurich. This publication is of the greatest value because of the great variety of fuel analyses given, and especially because all experiments have been carried out by uniform methods. Great credit is undoubtedly due to the institution for its exceedingly meritorious research work in the fields of scientific fuel testing.

In order to verify the degree of accuracy of our method of calculation, we have checked this method with the 205 kinds of oil mentioned in the above publication, with the following results:

(*a*) HEAT OF VAPORISATION OF WATER OF COMBUSTION.

The maximum divergence above and below the curve values was found to be for—

Petroleum oils	32	calories.
Mexican and Californian oils	70	,,
Lignite tar oils and shale oils	100	,,
Bohemian lignite tars	32	,,
Vegetable oils	25	,,
Oil gas tars	38	,,
Coal tar oils	26	,,
Coal tars	62	,,

This shows that the greater divergences only occur with those oils less frequently used, while the errors of this method of calculation are quite insignificant for the more commonly used oils. The error per cent. in calorific value amounts at the most to 0·32 per cent. with petroleum oils, and 0·29 per cent. with coal tar oils.

(*b*) CALORIFIC VALUE OF WATER-FREE OILS.

Divergence from Curve Values. Calories:	0 to 50	50 to 100	100 to 150	150 to 200	200 to 250	
	Number of Oils.					*Total*
Petroleum oils ..	54	27	11	1[1]	—	93
Per cent.	58	29	12	1	—	100
Mexican and Californian oils	4	2	—	2[2]	—	8
Per cent.	50	25	—	25	—	100
Lignite tar and shale oils	2	3	—	2[3]	1[4]	8
Per cent.	25	37·5	—	25	12·5	100
Bohemian lignite tars	3	1	—	—	—	4
Per cent.	75	25	—	—	—	100
Vegetable oils	3	1	—	—	—	4
Per cent.	75	25	—	—	—	100
Oil gas tars and carburetted water gas tars	6	7	4	—	—	17
Per cent.	35	41	24	—	—	100
Coal tar oils	9	17	—	2[5]	—	28
Per cent.	32	61	—	7	—	100
Coal tars	33	9	—	1[6]	—	43
Per cent.	77	21	—	2	—	100

MAXIMUM DIVERGENCES.

No.*				
1	92.	Argentine crude oil	196 calories	too low.
2	83.	Californian residuum	173 ,,	,,
	88.	Mexican crude oil	166 ,,	too high.
3	110.	Fuel oil "Messel"	184 ,,	too low.
	115.	Scotch crude oil	189 ,,	too high.
4	114.	Creosote oil	227 ,,	too low.
5	121.	Tar oil (the greater part of the phenols extracted)	200 ,,	,,
	128.	Tar oil, Lens collieries	198 ,,	,,
6	165.	Vertical retort tar	200 ,,	,,

---

* These numbers correspond to those used by Constam and Schläpfer.

Here, also, the greater divergences are found only in the oils least used.

In order to obtain values which are certain not to exceed the actual calorific values, we recommend the reduction of the curve values by the following amounts:

Petroleum oils, oil gas tars, and carburetted water gas tars	150	calories.
Mexican and Californian petroleum oils	170	„
Lignite tars and shale oils	190	„
Vegetable oils	100	„
Coal tar and tar oils, Bohemian lignite tars	100	„

DETERMINATION OF THE WATER CONTENT.

One hundred grammes of oil are placed in a closed vessel and gradually raised to a temperature of about 150° C. The water present is driven off in the form of steam, and at the same time the other components of the oil which have low boiling-points are evaporated. The vapours are passed through a condenser (a water-cooled glass or metal tube), where they are liquefied and collected in a graduated measuring glass. Here the condensed water and oil separate from each other because of their different specific gravities, and settle in two easily discernible layers. The number of cubic centimetres of water directly indicates the water percentage of the oil sample.

This test may be made in a glass vessel, but preferably in a metallic vessel, which is more suitable for high temperatures. The metallic vessel is fitted with a stirring device.

Figs. 20 and 21 show an apparatus which is equally suitable for determining the water content and the amount of residue. It consists of a strong cast iron

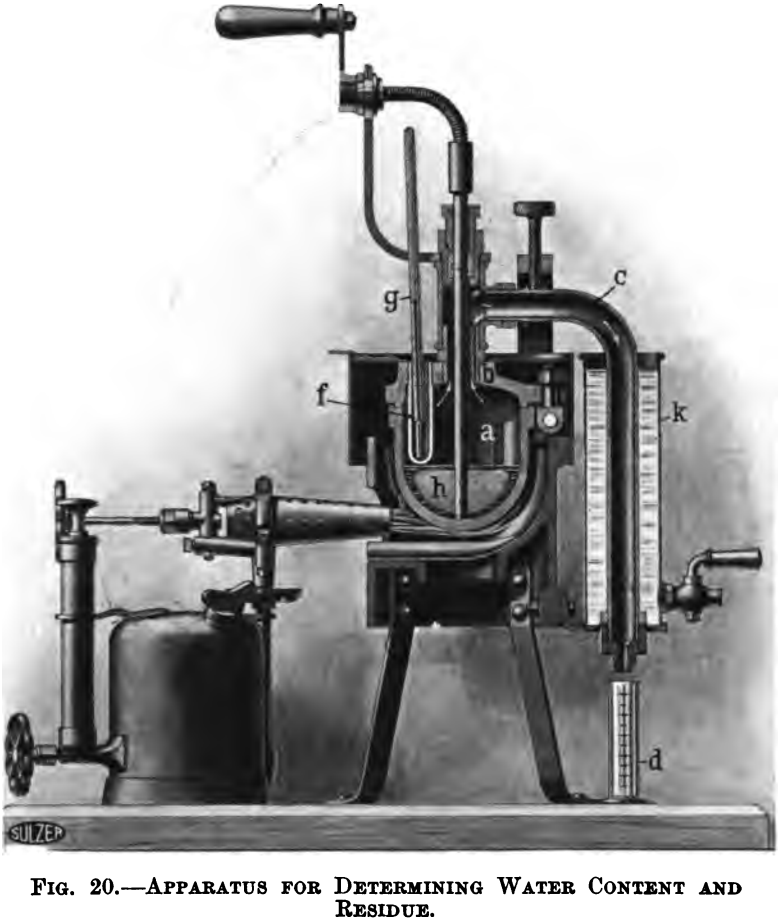


FIG. 20.—APPARATUS FOR DETERMINING WATER CONTENT AND RESIDUE.

vessel, *a*, of 400 c.c. capacity, closed by a cover, *b*, which is held down by two screws. From the centre of the cover an outlet pipe, *c*, conducts the vapours to the condenser, *k*, where they become liquefied.

The products of condensation drip into the measuring cylinder, *d*. The cover *b* is fitted with a tube, *f*, closed at the lower end, for the reception of the thermometer *g*. A stirrer, *h*, is situated inside the vessel, and is driven by a handle, through a flexible connection. The vessel may be heated either underneath by a spirit lamp, or from the side by a

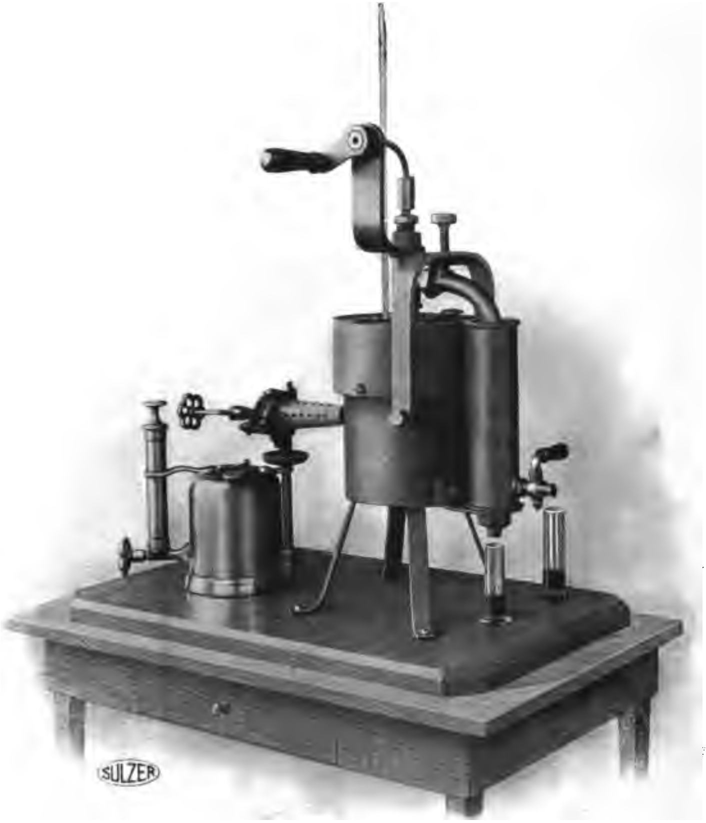


FIG. 21.—APPARATUS FOR DETERMINING WATER CONTENT AND RESIDUE.

petrol blow lamp. The vessel *a* and the condenser *k* are firmly fixed in a metallic casing supported on a tripod.

They are easily accessible, and the vessel and cover readily removable. When carrying out the test, especially with a fuel of considerable water content, care must be taken to prevent frothing over. This applies especially to tars. If, in spite of every care, such frothing should occur, it is advisable to reduce the sample quantity to 50 grammes. The stirrer should be moved continuously at 60 to 100 revolutions per minute during the boiling. The number of drops issuing from the condenser should not exceed one every three, or at most every two, seconds.

Evaporation Residues.—After all water has been driven off, the temperature may be gradually raised while the agitator is kept in motion at thirty to fifty revolutions per minute. The heating may be forced to some extent, as the danger of frothing is now slight. From 300° C. upwards new difficulties may be encountered, as the liquid now becomes thickened, impeding the escape of vapour, and is therefore likely to swell and form a spongy mass.

According to the standard chosen by Constam and Schläpfer, the final temperature of distillation should be 350° C. for coal tars and tar oils, oil gas tars and carburetted water gas tars, and vegetable oils; 400° C. for petroleum oils and distillates, lignite tars and shale oils and their distillates.

If the temperature of the condenser is too low, it may easily get choked up with naphthalene or paraffin. These deposits may be reliquefied by allowing the cooling water to acquire a higher temperature. It is advisable to make sure before every test that all passages are perfectly free. It is not at all necessary to continue the test till the very last drop of distillate comes over, provided that the limit temperature is attained, but it is very desirable that all tests should last about the same time. For a sample of 100 grammes the duration should be from thirty to forty minutes, reckoned from when the water is all driven off. The heat of the flame should be adjusted in such a manner that the maximum temperature is attained after about thirty minutes, and that this temperature is maintained for some three to five minutes before terminating the test. The quantity of residue is determined either by direct weighing or by weighing the vessel before and after emptying. One gramme of residue represents 1 per cent., provided that the sample quantity was 100 grammes.

Ash Content.—This is found by further heating the residue up to a bright red heat, whereby it is transformed into a coke-like body, from which all combustible components must be burned out, until, finally, only non-combustible matter, or "ash," is left. As the coke burns with difficulty, it is necessary for the high temperature to be continued for a considerable time, which is best done in a thin-walled crucible of porcelain or, still better, of nickel or platinum. The burning is facilitated by placing the crucible in an inclined position (Fig. 22), and a petrol blow lamp may be used when a Bunsen burner is not available. Care must be taken that none of the ash residue is carried away by currents of air. If the ash determination is carried out after the water and residue test, and from an initial quantity of 100 grammes of oil, the ash percentage is directly represented by the number of grammes. As this value is mostly less than 0·05 gramme, the balance used must be sufficiently sensitive to allow the reading of one-hundredth part of a gramme.

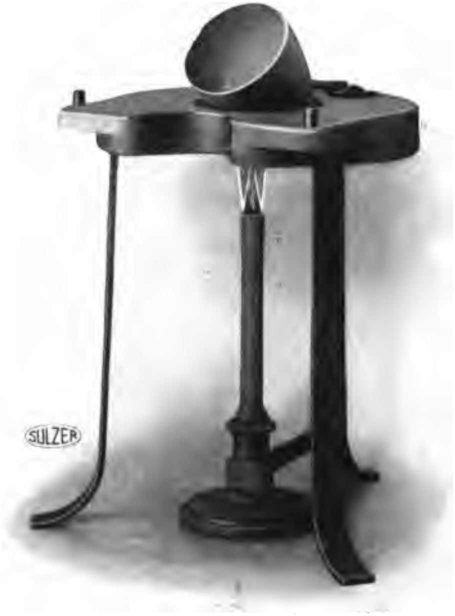


FIG. 22.—TESTING FOR ASH CONTENT.

Sulphur Content.—This test requires the use of a combustion apparatus. The sulphur compounds of the combustion gases are absorbed by bromine water, and the resultant sulphuric acid is precipitated by means of a barium chloride solution. One gramme weight of precipitate corresponds to 0·137 gramme of sulphur. When testing heavy oils, care must be taken to ensure that combustion is quite complete, and that no combustible residuum is left, as most of the sulphur is contained in the coke residue. This may be easily verified when testing fuels with high sulphur content.

To illustrate this we give an example of a Mexican oil of specific gravity 0·935 and average sulphur content of 2·9 per cent. by weight.

The analysis of the fractions of a distillation test showed—

Sulphur content of the fraction 100° to 150° C.= —
,, ,, ,, 150° to 200° C.=0·4 per cent.
,, ,, ,, 200° to 250° C.=0·4 ,,
,, ,, ,, 250° to 300° C.=0·8 ,,
,, ,, ,, above 300° C.=1·9 ,,
Sulphur content of the coke residue =8·3 ,,

The coke residue amounted to 20·2 per cent. of the original weight of sample. This is an ample proof that incomplete combustion may greatly vitiate the determination of the sulphur content.

The following is a description of an arrangement which is very convenient for determining the sulphur content of illuminating oils (Fig. 23): *a* is a burner with a small wick, filled with the oil to be tested.

The combustion gases are drawn through an absorption bottle, *b*, by means of a small water-jet aspirator, *c*.

The complete test requires several hours, as the sulphur content of petroleum lamp oil is very small (0·01 to 0·05 per cent.). Unfortunately, this experiment is not readily adaptable for testing heavy fuel oils, for these contain considerable quantities of components of high boiling point, which carbonise on the wick and impede the ascent of the already high viscous oils, so that the wick is likely to become

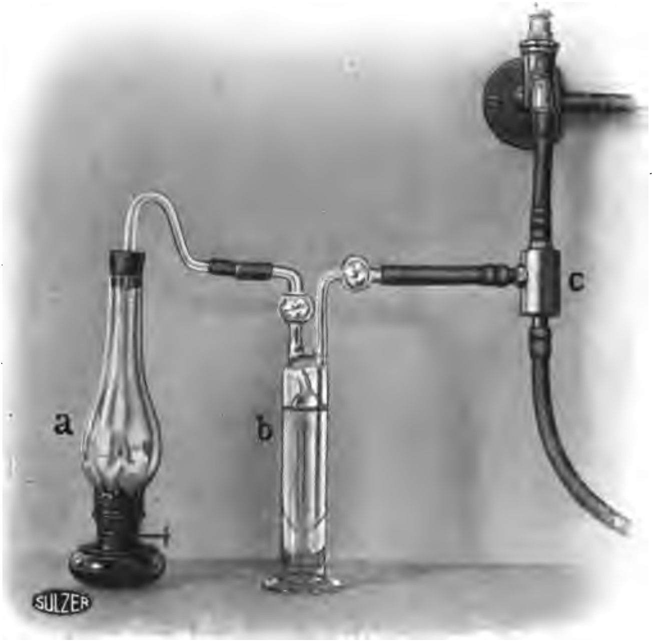


Fig. 23.—Testing for Sulphur Content.

clogged. Among the Diesel fuels there are only the petroleum oils of which the sulphur content might give rise to some hesitation as regards their employment. When heavy oils, including asphaltic oils, are to be tested, it is possible to make use of the procedure described above if the heavy oil is mixed with refined kerosene, but even such dilution does not entirely do away with the difficulty mentioned, and the wick must be raised from time to time. On the other hand, the duration of the test is generally shorter than with pure illuminating oil.

The sulphur content of the lamp petroleum used may be neglected in the calculation, but, of course, there would be no difficulty in allowing for this by separate testing of the diluting medium. The incrustation of the wick is always the cause of some inaccuracy whereby the sulphur content comes out rather too small, and an error of up to 10 per cent. may result. This is counterbalanced to some extent if the sulphur content of the lamp petroleum is neglected.

Light gas oils should be diluted with their own weight of kerosene, but heavy oils containing much asphalt require three to five times their weight of the diluting medium.

The absorption liquid is prepared in the following manner: To 300 c.c. of distilled water are added 15 grammes of potassium hydrate (KOH), or 30 c.c. of a solution of caustic potash of a specific gravity of 1·53 (50° Baumé), or 15 grammes of potassium carbonate (K_2CO_3). These reagents should be chemically pure, or at least free from sulphur. To this solution bromine is added drop by drop, until the liquid acquires a light yellow colour. The vapour of bromine is excessively irritating, so that all experiments with that substance should be performed out of doors. About 10 to 12 drops of bromine must be added to each 100 c.c. of solution. Fill the absorption bottle with about 40 c.c. of this liquid, and the receiver of the lamp with diluted fuel well up to one-half. Weigh the lamp and fuel as accurately as possible, and join up the whole apparatus. Start the aspirator, light the wick, and adjust the flame so that it does not smoke. If the flame does not burn well, the lamp glass may be taken off and the wick scraped down, but this should not be done too often, as the charred wick contains sulphur, which, of course, should be completely burned. The experiment may be continued for about two hours; by that time about 5 to 7 grammes of fuel will have been consumed.

The following account of an actual test fully explains the procedure:

SULPHUR DETERMINATION OF A MEXICAN CRUDE OIL OF 0·934 SPECIFIC GRAVITY AT 20° C.

Take 1 part (by weight) of the oil and mix it with 5 parts of petroleum. Fill the lamp receiver and put on the burner, which must have an unused wick about 10 centimetres long. Allow the wick to soak for about five minutes, and then remove the burner from the receiver and keep it suspended so that the excess oil can drop off the wick. Meanwhile ascertain the weight of the receiver filled with oil (in this experiment 77·948 grammes).

Get the absorption bottle ready and start the aspirator; put on the burner and wick; light it, and put on the lamp glass. The height of the flame should be adjusted to about $\frac{3}{8}$ inch. Should the flame go out by accident during the test, take off the lamp glass and relight the wick. This will have no appreciable influence on the result of the experiment. After two hours the test may be concluded, and on stopping the aspirator the flame will go out. Lift the burner out again, and allow the oil to drop from the wick into the receiver for about two minutes. Put the receiver with the oil again on the balance and ascertain its weight (in this case 71·742 grammes). The quantity of diluted oil consumed is therefore $77{\cdot}948 - 71{\cdot}742 = 6{\cdot}206$ grammes, and the corresponding amount of Mexican crude fuel oil is one-sixth of that, or $6{\cdot}206 \div 6 = 1{\cdot}034$ grammes.

Empty the absorption bottle and rinse out with about 60 c.c. of distilled water. Pour the absorption liquid and rinsing water into a glass vessel of about 0·3 litre capacity; add hydrochloric acid until the solution turns blue litmus paper red; then boil the liquid till the yellow colour disappears. Finally, add hot distilled water up to 250 c.c. total volume;

boil again, and add, drop by drop, hot barium chloride solution. The latter consists of 10 per cent. of barium chloride dissolved in distilled water, and about 10 c.c. of this solution should be used. Allow to stand fifteen minutes, and ascertain whether the quantity of barium chloride which has been added is sufficient (there should be a small excess). Put a drop of the treated liquid on a watch glass, together with a drop of sulphuric acid. It becomes cloudy if sufficient barium chloride has been added, but remains clear if there is too little. In the latter case more must be added, and the test repeated. Now allow the mixture to stand for twelve to twenty-four hours, during which time a white precipitate consisting of barium sulphate will have settled. The contents of the vessel are now filtered through an ash-free filter paper (of the thick and close-grained variety). Rinse the vessel several times with distilled water and pass this likewise through the filter. Then put the filter paper and precipitate into a porcelain crucible which has previously been weighed empty, and proceed to heat until the filter paper is entirely burned and only dry sulphate of barium is left.

This weighed, in the present case, 0·2364 gramme. As 1 gramme of barium sulphate corresponds to 0·137 gramme of sulphur, we find the quantity of sulphur in the precipitate to be $= 0{\cdot}2364 \times 0{\cdot}137 = 0{\cdot}0324$ gramme. The sulphur content of the oil is therefore $0{\cdot}0324 \times 100 \div 1{\cdot}034 = 3{\cdot}13$ per cent.

Free Carbon and Solid Impurities.—A very simple method of demonstrating the existence of solid impurities is to pour a few drops of the oil on to white paper. The oil is absorbed by the paper, while the solid impurities produce dark-coloured spots. Coal tars produce brownish-black spots, which often require several days to dry in, and finally acquire a lacquer-like gloss. *Soot* contained in oil leaves dull black spots. This simple experiment is also useful for the rough testing of used lubricating oils.

Test of Coal Tar.—Place a few cubic centimetres of coal tar in a test tube together with an equal volume of petroleum or gas oil and shake it briskly for a short time: pitch deposits will soon manifest themselves (Fig. 24). It is not difficult to estimate roughly the pitch content of a raw tar in this manner.

Add 50 grammes of tar to about 50 grammes of gas oil; heat the mixture up to about 60° or 80° C., and stir it with a glass rod. Allow it to stand for a short time till the pitch is settled. Pour off the liquid, and, after the residue has solidified, remelt once more. Some oil will collect again on the top, and must be poured off. The pitch, which will still contain a small percentage of gas oil, can now be weighed. It is possible to reduce the gas oil percentage considerably by repeated heating and pouring off. The author made use of this procedure some years ago on a large scale for abstracting the pitch from coal tars in order to obtain a good quality of Diesel fuel oil; 100 kilograms of inclined retort tar mixed with 40 kilograms of Galician gas oil yielded 95 kilograms of Diesel fuel oil and 45 kilograms of pitch. Pitch obtained in this way contains a considerable amount of oil. It has therefore poor adhesive qualities, and so can be used only as a furnace fuel.

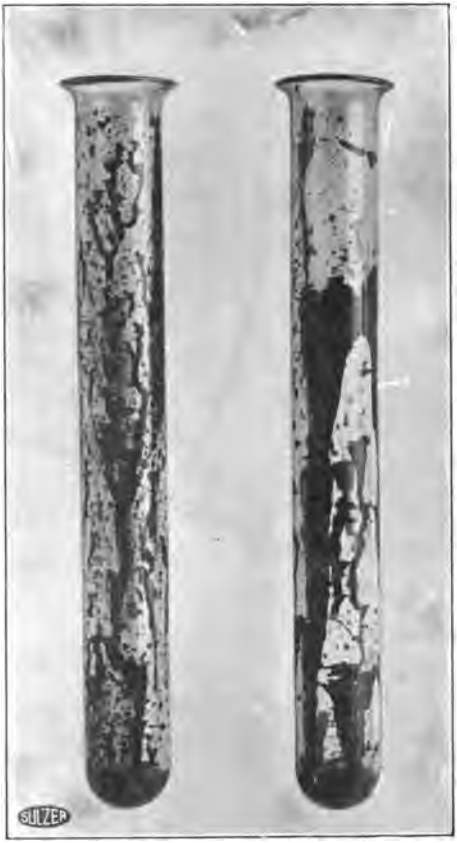


FIG. 24.

TAR FROM VERTICAL RETORTS. TAR FROM INCLINED RETORTS.

THE PRESENCE OF CRUDE TAR IN TAR OILS.

This can be easily detected by treatment with gas oil. Pour 1 or 2 drops of a mixture of tar oil and gas oil on white paper, and fine-grained dark specks will appear within the light brown oil spot if raw tar be present (Fig. 25). This will be still more clearly seen if a drop of the oil to be tested is poured on the paper and then a drop of gas oil added. The above illustrations show spots from tar oils containing 5, 10, and 20 per cent. of inclined retort tar.

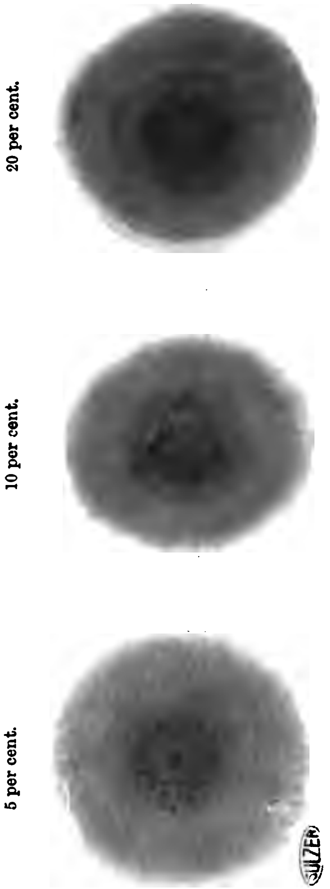


FIG. 25.—TAR OIL WITH AN ADMIXTURE OF 5, 10, AND 20 PER CENT. TAR.

ACID AND STABILITY TESTS OF LUBRICATING OILS.

Test for Free Mineral Acids.—Mix together about 20 c.c. of oil and 40 c.c. of distilled water, heat in a glass flask, and shake vigorously. Pour off the water into a second flask through a funnel lined with a folded and moistened filter paper. The oil of the mixture will be retained in the funnel. Now add a few drops of methyl orange indicator (0·3 gramme of methyl orange in 1 litre of water) to the water. A reddish colouring will be produced if acids are present. When an unused lubricating oil gives this reaction it may be concluded that sulphuric acid from the oil refining process is the cause of it. This, however, very seldom occurs, but in used lubricating oils the presence of free mineral acids is more likely.

Boiling Test.—Take two equal glass flasks of about 100 c.c. volume, and fill each of them about half full of oil. Place one of the flasks over a gas or spirit flame and carefully heat it until yellow vapours appear on the surface of the oil. This will occur at a temperature of 120° to 200° C., according to the nature of the oil. Maintain this boiling temperature for about twenty minutes by adjusting the flame.

Lubricating oils of good quality will, by this treatment, become somewhat darker in colour, but otherwise remain transparent and clear, and will not form any deposit even after standing a long time.

On the other hand, oils which are sensible to heat will become quite dark in colour, or even black, and will show a black sediment after standing for twenty-four hours.

The second glass flask serves only for judging the change in the colour by treatment. Such tests should not be made in ordinary glass vessels liable to crack at high temperatures, but in thin-walled glass flasks as used in chemical laboratories. Transformer oils are generally tested as described above. For transformers preference must certainly be given to oils which are heat resisting, but lubricating oils for bearings cannot be judged solely by this quality. This test, however, combined with the resinification test, will always give valuable indications as to the behaviour of the oil during prolonged service. Cylinder oils also should not be judged only by the results of the boiling test.

Resinification Test.—Spread a thin film of oil on a glass plate about 15 centimetres square, and keep the plate for some days in a horizontal position at a constant temperature of about 50° C. in a place as free as possible from dust. The samples are to be inspected every day, and the process of resinification tested by lightly touching with the finger. By the results the resisting power of the oil to resinification may be judged. The original oil film should not reach to the edge of the plate, as it has a tendency to spread in the warmth. The plates may be stored in the neighbourhood of the exhaust piping, but a better method is to have a heating cupboard (Fig. 26) which can hold a number of plates, and be placed near the exhaust piping. The top cover, which may be of wood, is fitted with a thermometer, and should be pierced by a vent-hole of about ¼ inch diameter, and a similar hole should be in the bottom of the cupboard. The box should be heat-insulated, for example, by placing it inside a second, larger sheet iron box, and filling the space between

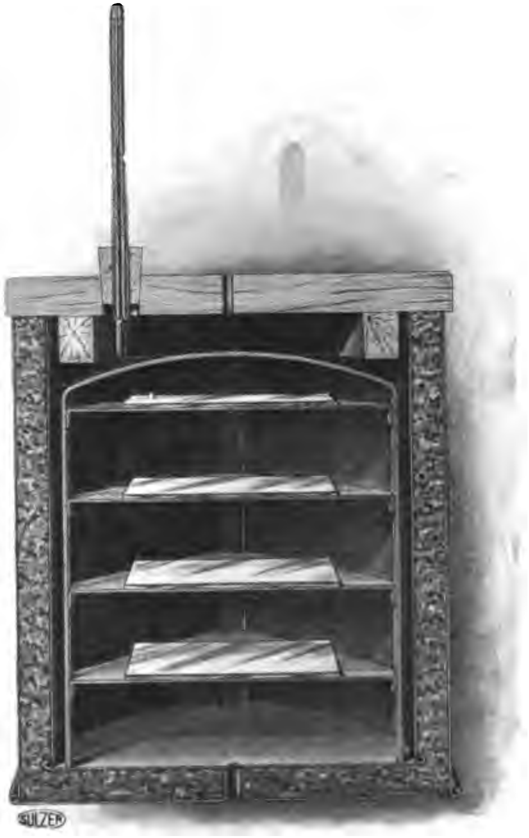


FIG. 26.—HEATING CUPBOARD FOR RESINIFICATION TEST.

with kieselguhr or a similar non-conducting substance. The shelves on which the plates are placed can easily be taken in and out of the cupboard.

It is always advisable to put in, along with the test plate, a sample plate of a good oil known to have little tendency to resinification, to serve as a standard for comparison. The resinification test applies mainly to bearing oils, and is not of great importance for cylinder lubricating oils.

APPENDIX

TABLE FOR THE CONVERSION OF DEGREES CENTIGRADE INTO DEGREES FAHRENHEIT.

1° C.=9/5° F. 1° F.=5/9° C.

Note.—The freezing point of water=0° C.=32° F.

Degrees.		*Degrees.*		*Degrees.*		*Degrees.*	
Centigrade.	*Fahrenheit.*	*Centigrade.*	*Fahrenheit.*	*Centigrade.*	*Fahrenheit.*	*Centigrade.*	*Fahrenheit.*
0	32·0	21	69·8	42	107·6	63	145·4
1	33·8	22	71·6	43	109·4	64	147·2
2	35·6	23	73·4	44	111·2	65	149·0
3	37·4	24	75·2	45	113·0	66	150·8
4	39·2	25	77·0	46	114·8	67	152·6
5	41·0	26	78·8	47	116·6	68	154·4
6	42·8	27	80·6	48	118·4	69	156·2
7	44·6	28	82·4	49	120·2	70	158·0
8	46·4	29	84·2	50	122·0	71	159·8
9	48·2	30	86·0	51	123·8	72	161·6
10	50·0	31	87·8	52	125·6	73	163·4
11	51·8	32	89·6	53	127·4	74	165·2
12	53·6	33	91·4	54	129·2	75	167·0
13	55·4	34	93·2	55	131·0	76	168·8
14	57·2	35	95·0	56	132·8	77	170·6
15	59·0	36	96·8	57	134·6	78	172·4
16	60·8	37	98·6	58	136·4	79	174·2
17	62·6	38	100·4	59	138·2	80	176·0
18	64·4	39	102·2	60	140·0	81	177·8
19	66·2	40	104·0	61	141·8	82	179·6
20	68·0	41	105·8	62	143·6	83	181·4

TABLE FOR THE CONVERSION OF DEGREES CENTIGRADE INTO DEGREES FAHRENHEIT—*Continued.*

1° C.=9/5° F. 1° F.=5/9° C.

Note.—The freezing point of water=0° C.=32° F.

Degrees.		*Degrees.*		*Degrees.*		*Degrees.*	
Centigrade.	*Fahrenheit.*	*Centigrade.*	*Fahrenheit.*	*Centigrade.*	*Fahrenheit.*	*Centigrade.*	*Fahrenheit.*
84	183·2	114	237·2	143	289·4	172	341·6
85	185·0	115	239·0	144	291·2	173	343·4
86	186·8	116	240·8	145	293·0	174	345·2
87	188·6	117	242·6	146	294·8	175	347·0
88	190·4	118	244·4	147	296·6	176	348·8
89	192·2	119	246·2	148	298·4	177	350·6
90	194·0	120	248·0	149	300·2	178	352·4
91	195·8	121	249·8	150	302·0	179	354·2
92	197·6	122	251·6	151	303·8	180	356·0
93	199·4	123	253·4	152	305·6	181	357·8
94	201·2	124	255·2	153	307·4	182	359·6
95	203·0	125	257·0	154	309·2	183	361·4
96	204·8	126	258·8	155	311·0	184	363·2
97	206·6	127	260·6	156	312·8	185	365·0
98	208·4	128	262·4	157	314·6	186	366·8
99	210·2	129	264·2	158	316·4	187	368·6
100	212·0	130	266·0	159	318·2	188	370·4
101	213·8	131	267·8	160	320·0	189	372·2
102	215·6	132	269·6	161	321·8	190	374·0
103	217·4	133	271·4	162	323·6	191	375·8
104	219·2	134	273·2	163	325·4	192	377·6
105	221·0	135	275·0	164	327·2	193	379·4
106	222·8	136	276·8	165	329·0	194	381·2
107	224·6	137	278·6	166	330·8	195	383·0
108	226·4	138	280·4	167	332·6	196	384·8
109	228·2	139	282·2	168	334·4	197	386·6
110	230·0	140	284·0	169	336·2	198	388·4
111	231·8	141	285·8	170	338·0	199	390·2
112	233·6	142	287·6	171	339·8	200	392·0
113	235·4						

One British Thermal Unit=B.Th.U.=the quantity of heat necessary to raise the temperature of 1 pound of water 1° F.

$$1 \text{ calorie} = \frac{1}{0{\cdot}453593} \times \frac{9}{5} = 3{\cdot}96828 \text{ B.Th.U.}$$

$$10{,}000 \text{ calories per kilogram} = \frac{10{,}000}{0{\cdot}453593} \times \frac{9}{5} \times 0{\cdot}453593$$
$$= 18{,}000 \text{ B.Th.U. per pound.}$$

Calories Per Kilogram.	*British Thermal Units Per Pound.*	*Calories Per Pound.*
8,000	14,400	3628·8
8,100	14,580	3674·1
8,200	14,760	3719·5
8,300	14,940	3764·9
8,400	15,120	3810·2
8,500	15,300	3355·6
8,600	15,480	3900·9
8,700	15,660	3946·3
8,800	15,840	3991·6
8,900	16,020	4037·0
9,000	16,200	4082·4
9,100	16,380	4127·7
9,200	16,560	4173·1
9,300	16,740	4218·4
9,400	16,920	4263·8
9,500	17,100	4309·2
9,600	17,280	4354·5
9,700	17,460	4399·9
9,800	17,640	4445·2
9,900	17,820	4490·6
10,000	18,000	4535·9
10,100	18,180	4581·3
10,200	18,360	4626·6
10,300	18,540	4672·0
10,400	18,720	4717·4
10,500	18,900	4762·7
10,600	19,080	4808·1
10,700	19,260	4853·4
10,800	19,440	4898·8
10,900	19,620	4944·2
11,000	19,800	4989·5

TABLE FOR THE CONVERSION OF MEASURES OF VARIOUS COUNTRIES.

Measures of Length.

1 inch English	= 25·3995 millimetres ..	1 millimetre	= 0·0394 inch.
1 foot = 12 inches	= 304·7945 „ ..	1 metre	= 3·2809 feet.
1 yard = 3 feet	= 0·9144 metre ..	1 „	= 1·0936 yard.
1 Vershok Russian	= 44·4494 millimetres ..	1 millimetre	= 0·0225 vershok.
1 Arshin = 16 vershok	= 0·7112 metres ..	1 metre	= 1·4061 arshin.
1 Sazhen = 3 arshin = 7 feet English	= 2·1336 metres ..	1 metre	= 0·4687 sazhen.

Measures of Capacity.

1 cubic inch English	= 16·3862 cubic centimetres ..	1 cubic centimetre	= 0·0610 cubic inch.
1 cubic foot	= 28·3154 cubic decimetres ..	1 cubic decimetre	= 0·0353 cubic foot.
1 Imperial gallon (= 10 lb. water)	= 4·5435 litres ..	1 litre	= 0·2201 Imperial gallon.
1 U.S.A. gallon	= 3·7852 „ ..	1 ..	= 0·2642 U.S.A. gallon.
1 Vedro Russian	= 12·299 „ ..	1 „	= 0·0813 vedro.
1 Chetvert	= 2·099 hectolitres ..	1 hectolitre	= 0·4764 chetvert.
1 Bochka Russian (barrel) = 40 vedro	= 4·9195 hectolitres ..	1 hectolitre	= 0·2033 bochka.

Weights.

1 pound avoirdupois (lb.) English = 7,000 grains	= 453·5926 grammes ..	1 kilogram	= 2·2046 pounds.
1 grain	= 0·0646 gramme		
1 hundredweight (cwt.) = 112 lbs.	= 50·8024 kilograms ..	1 kilogram	= 0·0197 cwt.
1 metric ton	= 1000 kilograms		
1 ton (long ton) = 20 cwts. = 2,240 lbs.	= 1016·047 kilograms ..	1 metric ton	= 0·9842 ton.
1 Funt Russian (pound)	= 0·4095 kilogram ..	1 kilogram	= 2·4420 funt.
1 Pood Russian	= 16·3805 kilograms ..	1 „	= 0·0610 pood.

Barrels.

Contents = 42 Imperial gallons.
= 50 American gallons.
= 190 litres (approx.)
Weight empty = 33 to 37 kg.
= 73 to 81 lb.
Average weight empty = 35 kg. = 77 lb.

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